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FRAGMENTS OF SCIENCE

A SERIES OF DETACHED ESSAYS, ADDRESSES
AND REVIEWS.

BY

JOHN TYNDALL, F.R.S.

FIFTH EDITION.

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PREFACE

TO

NEW EDITION.

IN VIEW of the present edition of these 'Fragments,' I have carefully re-examined, recast, and to some extent remodelled them, adding some new ones to those published in former editions.

In regard to style they are as clear and simple as I could make them. In regard to matter my desire has been that they should utter nothing base.

JOHN TYNDALL.

ATHENÆUM CLUB: *March* 24, 1876.

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PREFACE

TO

THE FIRST EDITION.

MY MOTIVE in writing these papers was mainly that which prompted the publication of my Royal Institution lectures; a desire, namely, to extend sympathy for science beyond the limits of the scientific public.

I have carefully looked over all the articles here printed, added a little, omitted a little—in fact, tried as far as my time permitted to render the work presentable. Most of the essays are of a purely scientific character; and from those which are not, I have endeavoured, without veiling my convictions, to exclude every word that could cause needless irritation.

From America came the impulse which induced me to gather these 'Fragments' together, and to my friends in the United States I dedicate them.

JOHN TYNDALL.

ATHENÆUM CLUB: *March* 1871.

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THE OPTICAL CONDITION OF THE ATMOSPHERE, IN ITS BEARINGS ON PUTREFACTION AND INFECTION.[1]

AN enquiry into the decomposition of vapours by light, begun in 1868 and continued in 1869, in which it was necessary to employ optically pure air, led me to experiment on the floating matter of the atmosphere. A brief section of a paper published in the 'Philosophical Transactions' for 1870 is devoted to this subject.

I at that time found that London air, which is always thick with motes, and also with matter too fine to be described as motes, after it had been filtered by passing it through densely packed cotton-wool, or calcined by passing it through a red-hot platinum tube containing a bundle of red-hot platinum wires, or by carefully leading it over the top of a spirit-lamp flame, showed, when examined by a concentrated luminous beam, no trace of mechanically suspended matter. The particular portion of space occupied by such a beam was not to be distinguished from adjacent space.

The purely gaseous portion of our atmosphere was thus shown to be incompetent to scatter light.

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[1] I have held back the publication of this edition of the 'Fragments,' so as to embrace among them some account of this investigation. The previous completion of the rest of the volume has rendered the separate paging of this chapter necessary.

I subsequently found that, to render the air thus optically pure, it was only necessary to leave it to itself for a sufficient time in a closed chamber, or in a suitably closed vessel. The floating matter gradually attached itself to the surrounding surfaces, leaving behind it air possessing no scattering power. Sent through such air, the most concentrated beam failed to render its track visible.

The parallelism of these results with those obtained in the excellent researches of Schwann, Schroeder and Dusch, Schroeder himself, and of the illustrious Pasteur, in regard to the question of 'spontaneous generation,' caused me to conclude that the power of scattering light and the power of producing life by the air would be found to go hand-in-hand.

This conclusion was strengthened by an experiment easily made and of high significance in relation to this question. It had been pointed out by Professor Lister, of Edinburgh, that air which has passed through the lungs is known to have lost its power of causing putrefaction. Such air may mix freely with the blood without risk of mischief; and that truly great scientific surgeon had the penetration to ascribe this immunity from danger to the filtering power of the lungs. Prior to my becoming acquainted with this hypothesis in 1869, I had virtually demonstrated its accuracy in the following way:

Condensing in a dark room, and in dusty air, a powerful beam of light, and breathing through a glass tube (the tube actually employed was a lamp-glass, rendered warm in a flame to prevent precipitation) across the focus, a diminution of the scattered light was first observed. But towards the end of the expiration the white track of the beam was broken by a perfectly black gap, the blackness being due to the total absence from the expired air of any matter competent to scatter light. The deeper portions of the lungs were thus proved to be filled with optically pure air, which, as such, had no power to generate the organisms essential to the process of putrefaction.[1]

I thought this simple method of examination could not fail to be of use to workers in this entangled field. They had hitherto proceeded less by sight than by insight, being in general unable to see the physical character of the medium in which their experiments were conducted. But the method has not been much turned to account; and this year, while preparing these 'Fragments' for publication, I was so impressed by its possible importance, that I resolved to devote some time to the more complete demonstration of its utility.

My principal stimulus, however, was the desire to free my mind, and, if possible, the minds of others, from the uncertainty and confusion which now beset the doctrine of 'spontaneous generation.' Pasteur has pronounced it a 'chimera,' and expressed the undoubting conviction that, this being so, it is possible to remove parasitic diseases from the earth. To the medical profession, therefore, and through them to humanity at large, this question is one of the last importance. But the state of medical opinion regarding it is not satisfactory. In a recent number of the 'British Medical Journal,' and in answer to the question, 'In what way is contagium generated and communicated?' Messrs. Braidwood and

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[1] 'No putrefaction,' says Cohn, 'can occur in a nitrogenous substance if it be kept free from the entrance of new *Bacteria* after those which it may contain have been destroyed. Putrefaction begins as soon as *Bacteria*, even in the smallest numbers, are accidentally or purposely introduced. It progresses in direct proportion to the multiplication of the *Bacteria*; it is retarded when the *Bacteria* (for example, by a low temperature) develop a small amount of vitality, and is brought to an end by all influences which either stop the development of the *Bacteria* or kill them. All bactericidal media are therefore antiseptic and disinfecting.'—Beiträge zur Biologie der Pflanzen. Zweites Heft, 1872, p. 203.

Vacher reply that, notwithstanding 'an almost incalculable amount of patient labour, the actual results obtained, especially as regards the manner of generation of contagium, have been most disappointing. Observers are even yet at variance whether these minute particles, whose discovery we have just noticed, and other disease germs, are always produced from like bodies previously existing, or whether they do not, under certain favourable conditions, spring into existence *de novo*.'

With a view to the possible diminution of the uncertainty thus described, I have recently submitted to the Royal Society, and more especially to those who study the Ætiology of disease, a description of the mode of procedure followed in this enquiry, and the results to which it has led.

A number of chambers, or cases, were constructed, each with a glass front, its top, bottom, back, and sides being of wood. At the back is a little door which opens and closes on hinges, while into the sides are inserted two panes of glass, facing each other. The top is perforated in the middle by a hole 2 inches in diameter, closed air-tight by a sheet of india-rubber. This sheet is pierced in the middle by a pin, and through the pin-hole is passed the shank of a long pipette ending above in a small funnel. A circular tin collar, 2 inches in diameter and 1½ inch deep, surrounds the pipette, the space between both being packed with cotton-wool moistened by glycerine. Thus the pipette, in moving up and down, is not only firmly clasped by the india-rubber, but it also passes through a stuffing-box of sticky cotton-wool. The width of the aperture closed by the india-rubber secures the free lateral play of the lower end of the pipette. Into two other smaller apertures in the top of the chamber are inserted, air-tight, the open ends of two narrow tubes, intended to connect the interior space with the atmosphere. The tubes are bent several times up and down, so as to intercept and retain the particles carried by such feeble currents as changes of temperature might cause to set in between the outer and the inner air.

The bottom of the box is pierced, sometimes with two rows, sometimes with a single row of apertures, in which are fixed, air-tight, large test-tubes, intended to contain the liquid to be exposed to the action of the moteless air. The cases have varied in capacity from 1,666 to 451 cubic inches.

On September 10 the first case of this kind was closed. The passage of a concentrated beam across it through its two side windows then showed the air within it to be laden with floating matter. On the 13th it was again examined. Before the beam entered, and after it quitted the case, its track was vivid in the air, but within the case it vanished. Three days of quiet sufficed to cause all the floating matter to be deposited on the top, sides, and bottom, where it was retained by a coating of glycerine, with which the interior surface of the case had been purposely varnished. The test-tubes were then filled through the pipette, boiled for five minutes in a bath of brine or oil, and abandoned to the action of the moteless air. During dilution aqueous vapour rose from the liquid into the chamber, where it was for the most part condensed, the uncondensed portion escaping, at a low temperature, through the bent tubes at the top. Before the brine was removed little stoppers of cotton-wool were inserted in the bent tubes, lest the entrance of the air into the cooling chamber should at first be forcible enough to carry motes along with it. As soon, however, as the ambient temperature was assumed by the air within the case the cotton-wool stoppers were removed.

We have here the oxygen, nitrogen, carbonic acid, ammonia, aqueous vapour, and all the other gaseous matters which mingle more or less with the air of a great city. We have them, moreover, 'untortured' by calcination and unchanged even by filtration or manipulation of any kind. The question now before us is, Can air thus retaining all its gaseous mixtures, but self-cleansed from mechanically suspended matter, produce putrefaction in organic infusions freely exposed to its action? To this question both the animal and vegetable worlds return a decided negative.

Among vegetables experiments have been made with hay, turnips, tea, coffee, hops, repeated in various ways with both acid and alkaline infusions. Among animal substances are to be mentioned many experiments with urine; while beef, mutton, hare, rabbit, kidney, liver, fowl, pheasant, grouse, haddock, sole, salmon, cod, turbot, mullet, herring, whiting, eel, oyster have been all subjected to experiment.

The result is that infusions of these substances exposed to the common air of the Royal Institution laboratory, maintained at a temperature of from 60° to 70° Fahr., all fell into putrefaction in the course of from two to four days. No matter where the infusions were placed, they were infallibly smitten in the end. The number of the tubes containing infusions was multiplied till it reached six hundred, but not one of them escaped infection.

In no single instance, on the other hand, did the air, which had been proved moteless by the searching beam, even when raised to over 90°, manifest the least power of producing Bacterial life or the associated phenomena of putrefaction. The power of developing such life in atmospheric air, and the power of scattering light, are thus proved to be indissolubly united.

The sole condition necessary to cause these long-dormant infusions to swarm with active life is the access of the floating matter of the air. After having remained for four months as pellucid as distilled water, the opening of the back-door of the protecting case and the consequent admission of the mote-laden air, sufficed in three days to render the infusions putrid and full of life.

That such life arises from mechanically suspended particles is thus reduced to ocular demonstration.

Let us enquire a little more closely into the character of the particles which produce the life. Pour Eau de Cologne into water; a white precipitate renders the liquid milky. Or, imitating Brücke, dissolve clean gum mastic in alcohol, and drop it into water; the mastic is precipitated, and milkiness produced. If the solution be very strong the mastic separates in curds; but by gradually diluting the alcoholic solution we finally reach a point where the milkiness disappears, the liquid assuming, by reflected light, a bright cerulean hue. It is, in point of fact, the colour of the sky, and is due to a similar cause, namely, the scattering of light by particles, small in comparison to the size of the waves of light.

When this liquid is examined by the highest microscopic power it seems as uniform as distilled water. The mastic particles, though innumerable, entirely elude the microscope. At right angles to a luminous beam passing among the particles they discharge perfectly polarised light. The optical deportment of the floating matter of the air proves it to be composed in part of particles of this excessively minute character. When the track of a parallel beam in dusty air is looked at horizontally through a Nicol's prism, in a direction perpendicular to the beam, the longer diagonal of the prism being vertical, a considerable portion of the light from the finer matter is extinguished. The coarser motes, on the other hand, flash out with greater force, because of the increased darkness of the space around them. It is, I hold, among the finest ultra-microscopic particles that the matter potential as regards the development of Bacterial life is to be sought.

Now the existence of these particles, foreign to the atmosphere but floating in it, is as certain as if they could be felt between the fingers or seen by the naked eye. Supposing them to augment in magnitude until they come, not only within range of the microscope, but within range of the unaided senses. Let it be assumed that our knowledge of them under these circumstances remains as defective as it is now—that we do not know whether they are germs, particles of dead organic dust, or particles of mineral matter. Suppose a vessel (say a flower-pot) to be at hand filled with nutritious earth, with which we mix our unknown particles; and that in forty-eight hours subsequently buds and blades of well-defined cresses and grasses appear above the soil. Suppose the experiment when repeated over and over again to yield the same unvarying result. What would be our conclusion? Should we regard those living plants as the products of dead dust or mineral particles, or should we regard them as the offspring of living seeds? The reply is unavoidable. We should undoubtedly consider the experiment with the flower-pot as clearing up our pre-existing ignorance; we should regard the fact of their producing cresses and grasses as proof positive that the particles sown in the earth of the pot were the seeds of the plants which have grown from them. It would be simply monstrous to conclude that they had been 'spontaneously generated.'

This reasoning applies word for word to the development of *Bacteria* from that floating matter which the electric beam reveals in the air, and in the absence of which no Bacterial life has been generated. There seems no flaw in this reasoning; and it is so simple as to render it unlikely that the notion of Bacterial life developed from dead dust can ever gain currency among the members of a great scientific profession.

A novel mode of experiment has been here pursued, and it may be urged that the conditions laid down by other investigators in this field, which have led to different results, have not been strictly adhered to. To secure accuracy in relation to this point, I will quote the latest words of a writer on this question, who has materially influenced medical thought both in this country and in America. 'We know,' he says, 'that boiled turnip- or hay-infusions exposed to ordinary air, exposed to filtered air, to calcined air, or shut off altogether from contact with air, are more or less prone to swarm with *Bacteria* and vibriones in the course of from two to six days.' Who the 'we' are who possess this knowledge is not stated. I certainly am not among the number, though I have sought anxiously for knowledge of the kind. The statements were thus tested in succession.

And first, with regard to filtered air. A group of twelve large test-tubes was caused to pass air-tight through a slab of wood. The wood was coated with cement, in which, while hot, a heated 'propagating glass' resembling a large bell-jar was imbedded. The air within the jar was pumped out several times, air filtered through a plug of cotton-wool being permitted to supply its place. The test-tubes contained infusions of hay, turnip, beef, and mutton—three of each—twelve in all. After months of exposure they are as clear and cloudless to-day as they were upon the day of their introduction; while twelve similar tubes, prepared at the same time, in precisely the same way, and exposed to the ordinary air, are clogged with mycelium, mould, and *Bacteria*.

With regard to the calcined air, a similar propagating glass was caused to cover twelve other tubes filled with the same infusions. The 'glass' was exhausted and carefully filled with air, which had been slowly passed through a red-hot platinum tube, containing a roll of red-hot platinum gauze. Tested by the searching beam, the calcined air was found quite free from floating matter. Not a speck has invaded the limpidity of the infusions exposed to it, while twelve similar tubes placed outside have fallen into rottenness.

The experiments with calcined air took another form. Six years ago I found that, to render the laboratory air free from floating matter, it was only necessary to permit a platinum wire heated to whiteness to act upon it for a sufficient time. Shades, containing pear juice, damson juice, infusions of hay and turnip, and water of yeast, were freed from their floating matter in this way. The infusions were subsequently boiled and permitted to remain in contact with the calcined air. They are quite clear to the present hour, while the same infusions exposed to common air became mouldy and rotten long ago.

It has been affirmed by other writers on this question that turnip- and hay-infusions rendered slightly alkaline are particularly prone to exhibit the phenomena of spontaneous generation. This was not found to be the case in the present investigation. Many such infusions have been prepared, and they have continued for months without sensible alteration.

Finally, with regard to infusions wholly withdrawn from air, a group of test-tubes, containing different infusions, was boiled under a bell-jar first filled with filtered air, and from which the air was subsequently removed as far as possible by a good air-pump. They are now as pellucid as they were at the time of their preparation more than three months ago, while a group of corresponding tubes exposed to the laboratory air have all fallen into rottenness.

There is still another form of experiment on which great weight has been laid—that of hermetically sealed tubes. On April 6 last, a discussion on the 'Germ Theory of Disease' was opened before the Pathological Society of London. The meeting was attended by many distinguished medical men, some of whom were profoundly influenced by the arguments, and none of whom disputed the facts brought forward against the theory on that occasion. The following important summary of these was then given by Dr. Bastian: 'With the view of settling these questions, therefore, we may carefully prepare an infusion from some animal tissue, be it muscle, kidney, or liver; we may place it in a flask whose neck is drawn out and narrowed in the blowpipe-flame, we may boil the fluid, seal the vessel during ebullition, and, keeping it in a warm place, may await the result, as I have often done. After a variable time, the previously heated fluid within the hermetically sealed flask swarms more or less plentifully with *Bacteria* and allied organisms.'

Previous to reading this statement, I had operated upon sixteen tubes of hay- and turnip-infusions, and upon twenty-one tubes of beef, mackerel, eel, oyster, oatmeal, malt, and potato, hermetically sealed while boiling, not by the blowpipe, but by the far more handy spirit-lamp flame. In no case was any appearance whatever of *Bacteria* or allied organisms observed. The perusal of the discussion just referred to caused me to turn again to muscle, liver, and kidney, with a view of varying and multiplying the evidence. Fowl, pheasant, snipe, partridge, plover, wild-duck, beef, mutton, heart, tongue, lungs, brains, sweetbread, tripe, the crystalline lens, vitreous humour, herring, haddock, mullet, codfish, sole, were all embraced in the experiments. There was neither mistake nor ambiguity about the result. On January 13 one hundred and thirty-nine of the flasks operated on were submitted to the Fellows of the Royal Society, and not one of this cloud of witnesses offered the least countenance to the assertion that liquids within flasks, boiled and hermetically sealed, swarm, subsequently, more or less plentifully with *Bacteria* and allied organisms.

The evidence furnished by this mass of experiments, that Dr. Bastian must have permitted errors either of preparation or observation to invade his work, is, I submit, very strong. But to err is human; and in an enquiry so difficult and fraught with such momentous issues, it is not error, but the persistence in error by any of us for dialectic ends, that is to be deprecated. Let me here show by one or two illustrations the risks of error to which I have been exposed. On October 21 I opened the back-door of a case containing six test-tubes filled with an infusion of turnip which had remained perfectly clear for three weeks, while three days sufficed to crowd six similar tubes exposed to mote-laden air with *Bacteria.* With a small pipette I took specimens from the pellucid tubes, and placed them under the microscope. The first tube examined showed no signs of life. This was the result expected, but I was by no means prepared for the deportment of the second tube. Here the exhibition of life was monstrously copious. There were numerous globular organisms, which revolved, rotated, and quivered in the most extraordinary manner. There were also numbers of lively *Bacteria* darting to and fro. An experimenter who ponders his work and reaches his conclusions slowly, cannot immediately relinquish them; and in the present instance some time was required to convince me that I had made no mistake. I could find none, and was prepared to accept the conclusion that in the boiled infusion, despite its clearness, life had appeared.

But in a protected turnip-infusion, which had been examined on October 13, no trace of life could be found. In this case perfect transparency was accompanied by an er absence of life. Indeed the selfsame action upon ht that enabled the *Bacteria* to show themselves in e microscope must, one would think, infallibly pro-ce turbidity. Why, moreover, should life be absent m the first member of the present group of tubes? I rched this again, and found in it scanty but certain ns of life. This augmented my perplexity. A third be also showed scanty traces of life. Reverting to the ond tube, where life had been so copious, I found t in it the organisms had become as scanty as in the ers. I confined myself for a time to the three tubes of first row of the six, going over them again and again; netimes finding an organism here and there, but some-nes finding nothing. The first extraordinary exhibition life it was found impossible to restore. In my diffi-ty I took specimens from the three tubes and sent m to Professor Huxley, with a request that he would good enough to examine them.

On the 22nd my search was extended to the whole of tubes. Early in the day lively *Bacteria* were found in e of them; later on, not one of the six yielded to my sest scrutiny any trace of life. On the evening of the nd I received a note from Mr. Huxley stating that a eful examination of the specimens sent to him revealed living thing.

Pipettes had been employed to remove the solution m the test-tubes. They were short pieces of narrow ss tubing, drawn out to a point, with a few inches of lia-rubber tubing attached to them. This was found nvenient for bending so as to reach the bottom of the t-tubes. Suspicion fell upon this india-rubber. I shed it, and examined the washing-water, but found no e. Distilled water had been used to cleanse the pettes, and on the morning of the 23rd I entered the oratory, intending to examine it. Before dipping the pipette into the water I looked at its point. The tiniest drop had remained in it by capillary attraction from the preceding day. This I blew on to a slide, covered it, and placed it under the microscope. An astonishing exhibition of life was my reward. Thus on the scent, I looked through my pipettes, and found two more with the smallest residual drops at the ends; both of them yielded a field rampant with life. The *Bacteria* darted in straight lines to and fro, bending right and left along the line of motion, wriggling, rotating longitudinally, and spinning round a vertical transverse axis. Monads also galloped and quivered through the field. From one of these tiny specks of liquid I obtained an exhibition of life not to be distinguished from that which had astonished me on the 21st.

Obviously the phenomenon then observed was due to the employment of an unclean pipette. Equally obvious is it that in enquiries of this nature the experimenter is beset with danger, the grossest errors being possible when there is the least lack of care.

Again, three tubes, containing infusions of turnip, hay, and mutton, were boiled on November 2, under a bell-jar containing air so carefully filtered that the most searching examination by a concentrated beam failed to reveal a particle of floating matter. At the present time every one of the tubes is thick with mycelium and covered with mould. Here surely we have a case of spontaneous generation. Let us look to its history.

After the air has been expelled from a boiling liquid it is difficult to continue the ebullition without 'bumping.' The liquid remains still for intervals and then rises with sudden energy. It did so in the case now under consideration, and one of the tubes boiled over, the liquid overspreading the resinous surface in which the bell-jar was imbedded. For three weeks the infusions had remained perfectly clear. At the end of this time, with a view of renewing the air of the jar, it was exhausted, and refilled by fresh air which had passed through a plug of cotton-wool. As the air entered, two small spots of penicillium, resting on the liquid which had boiled over, attracted attention. I at once remarked that the experiment was a dangerous one, as the entering air would probably detach some of the spores of the penicillium and diffuse them in the bell-jar. This was, therefore, filled very slowly, so as to render the disturbance a minimum. Next day, however, a tuft of mycelium was observed at the bottom of one of the three tubes, namely that containing the hay-infusion. It has by this time grown so as to fill a large portion of the tube. For nearly a month longer the two tubes containing the turnip- and mutton-infusions maintained their transparency unimpaired. Late in December the mutton-infusion, which was in dangerous proximity to the outer mould, showed a tuft upon its surface. The turnip-infusion continued bright and clear for nearly a fortnight longer. The recent cold weather caused me to add a third gas-stove to the two which had previously warmed the room in which the experiments are conducted. The warmth played upon one side of the bell-jar, causing currents within it; and the day after the lighting of the stove, the turnip-infusion gave birth to a tuft of mycelium. In this case the small spots of penicillium might have readily escaped attention; and had they done so, we should have had three cases of 'spontaneous generation' far more striking than many that have been adduced.

In further illustration of the danger incurred in this field of enquiry, I may refer to the excellent paper of Dr. Roberts on Biogenesis, in the 'Philosophical Transactions for 1874.' Dr. Roberts fills the bulb of an ordinary pipette up to *about two-thirds* of its capacity with the infusion to be examined. In the neck of the pipette he places a plug of dry cotton-wool. He then hermetically seals the neck, and dips the bulb into boiling water, or hot oil, where he permits it to remain for the requisite time. Here we have no disturbance from ebullition, and no loss by evaporation. The bulb is removed from the hot water and permitted to cool. The sealed end of the neck is then filed off, the cotton-wool alone interposing between the infusion and the atmosphere.

The arrangement is beautiful, but it has one weak point. Cotton-wool free from germs is not to be found, and the plug employed by Dr. Roberts infallibly contained them. In the gentle movement of the air to and fro, as the temperature changed, or by any shock, jar, or motion to which the pipette might be subjected, we have certainly a cause sufficient to detach a germ now and then from the cotton-wool which, falling into the infusion, would produce its effect. Probably also condensation occurred at times in the neck of the pipette, the water of condensation carrying back from the cotton-wool the seeds of life. The fact of fertilisation being so rare, as Dr. Roberts found it to be, is a proof of the care with which his experiments were conducted. But he did find cases of fertilisation after prolonged exposure to the boiling temperature; and this caused him to come to the conclusion that under certain rare conditions spontaneous generation may occur. He also found that an alkalised hay-infusion was so difficult to sterilise that it was capable of withstanding the boiling temperature for hours without losing its power of generating life. Careful experiments have been made with this infusion. Dr. Roberts is certainly correct in assigning to it superior nutritive power. But in the present enquiry five minutes' boiling sufficed to completely sterilise the liquid.

I shall hardly be charged with any desire to limit the power and potency of matter in regard to life. On this point I have already expressed myself in a manner not to be mistaken. But, holding the notions I do, it is all the more incumbent on me to affirm that, as far as enquiry has hitherto penetrated, life has never been proved to appear independently of antecedent life.

With regard to the general diffusion of germs in the atmosphere, the notions entertained by distinguished writers rendered it desirable to place the point beyond question. At Down, Mr. Darwin and Mr. Francis Darwin; at High Elms, Sir John Lubbock; at Sherwood, near Tunbridge Wells, Mr. Siemens; at Pembroke Lodge, Richmond Park, Mr. Rollo Russell; at Heathfield Park, Miss Hamilton; at Greenwich Hospital, Mr. Hirst; at Kew, Dr. Hooker; and at the Crystal Palace, Mr. Price kindly took charge of infusions, every one of which was invaded, many by astounding swarms of organisms.

To obtain more definite insight regarding the diffusion of atmospheric germs a square wooden tray was pierced with 100 holes, into each of which was dropped a short test-tube. On October 23 thirty of these tubes were filled with an infusion of hay, thirty-five with an infusion of turnip, and thirty-five with an infusion of beef. The tubes, with their infusions, had been previously boiled, ten at a time, in an oil-bath. One hundred circles were marked on paper, so as to form a map of the tray, and every day the state of each tube was registered upon the corresponding circle. In the following description the term 'cloudy' is used to denote the first stage of turbidity, distinct but not strong; the term 'muddy' is used to denote thick turbidity.

One tube of the hundred was first singled out and rendered muddy. It belonged to the beef-group, and it was a whole day in advance of all the other tubes. The progress of putrefaction was first registered on October 26. The 'map' then taken may be thus described:

Hay.—Of the thirty specimens exposed one had become 'muddy'—the seventh in the middle row reckoning from the side of the tray nearest a stove. Six tubes remained perfectly clear between this muddy one and the stove, proving that differences of warmth may be overridden by other causes. Every one of the other tubes containing the hay-infusion showed spots of mould upon the clear liquid.

Turnip.—Four of the thirty-five tubes were very muddy, two of them being in the row next the stove, one four rows distant, and the remaining one seven rows away. Besides these, six tubes had become clouded There was no mould on any of the tubes.

Beef.—One tube of the thirty-five was quite muddy, in the seventh row from the stove. There were three cloudy tubes, while seven of them bore spots of mould.

As a general rule, organic infusions exposed to the air during the autumn remained for two days or more perfectly clear. Doubtless from the first germs fell into them, but they required time to be hatched. This period of clearness may be called the 'period of latency,' and indeed it exactly corresponds with what is understood by this term in medicine. Towards the end of the period of latency the fall into a state of disease is comparatively sudden; the infusion passing from perfect clearness to cloudiness more or less dense in a few hours.

Thus the tube placed in Mr. Darwin's possession was clear at 8.30 A.M. on October 19, and cloudy at 4.30 P.M. Seven hours, moreover, after the first record of our tray of tubes, a marked change had occurred. Instead of one, eight of the tubes containing hay-infusion had fallen into uniform muddiness. Twenty others had produced Bacterial slime, which had sunk to the bottom, every tube containing the slime being covered by mould. Three tubes only remained clear, but with mould upon their surfaces. The muddy turnip-tubes had increased from four to ten; seven tubes were clouded, while eighteen of them remained clear, with here and there a speck of mould on the surface. Of the beef, six were cloudy and one thickly muddy, while spots of mould had formed in the majority of the remaining tubes. Fifteen hours subsequent to this observation, viz. on the morning of October 27, all the tubes containing hay-infusion were smitten, though in different degrees, some of them being much more turbid than others. Of the turnip-tubes, three only remained unsmitten, and two of these had mould upon their surfaces. Only one of the thirty-five beef-infusion remained intact. A change of occupancy, moreover, had occurred in the tube which first gave way. Its muddiness remained grey for a day and a half, then it changed to bright yellow green, and it maintained this colour to the end. On the 27th every tube of the hundred was smitten, the majority with uniform turbidity; some, however, with mould above and slime below, the intermediate liquid being tolerably clear. The whole process bore a striking resemblance to the propagation of a plague among a population, the attacks being successive, and of different degrees of virulence.

From the irregular manner in which the tubes are infected we may infer that, as regards *quantity*, the distribution of the germs in the air is not uniform. The singling out, moreover, of one tube of the hundred by the particular *Bacteria* that develop a green pigment, shows that, as regards *quality*, the distribution is not uniform. The same absence of uniformity was manifested in the struggle for existence between the *Bacteria* and the penicillium. In some tubes the former were triumphant; in other tubes, of the same infusion, the latter was triumphant. It would seem also as if a want of uniformity *as regards vital vigour* prevailed. With the selfsame infusion the motions of the *Bacteria* in some tubes were exceedingly languid, while in other tubes they resembled a rain of projectiles, being so rapid and violent as to be followed with difficulty by the eye. Reflecting on the whole of this, I conclude that the germs float through the atmosphere in groups or clouds, with spaces more sparsely filled between them. The touching of a nutritive fluid by a Bacterial cloud would naturally have a different effect from the touching of it by the interspace between two clouds. But as, in the case of a mottled sky, the various portions of the landscape are successively visited by shade, so, in the long run, were the various tubes of the tray touched by the Bacterial clouds, the final fertilisation or infection of them all being the consequence. These results connect themselves with the experiments of Pasteur on the non-continuity of the cause of so-called spontaneous generation, and with other experiments of my own.[1]

On November 9 a second tray, containing 100 tubes filled with an infusion of mutton, was exposed to the air. On the morning of the 11th six of the ten nearest the stove had given way to putrefaction. Three of the row most distant from the stove had yielded, while here and there over the tray particular tubes were singled out and smitten by the infection. Of the whole tray of 100 tubes, twenty-seven were either muddy or cloudy on the 11th. Thus, doubtless, in a contagious atmosphere, are individuals successively struck down. On the 12th all the tubes had given way, but the differences in their contents were extraordinary. All of them contained *Bacteria*, some few, others in swarms. In some tubes they were slow and sickly in their motions, in some apparently dead, while in others they darted about with rampant vigour. These differences are to be referred to differences in the germinal matter, for the same infusion was presented everywhere to the air. Here also we have a picture of what occurs during an epidemic, the difference in number and energy of the Bacterial swarms resembling the varying intensity of the disease. It becomes obvious from these experiments that of two individuals of the same population, exposed to a contagious atmosphere, the one may be severely, the other lightly attacked, though the two individuals may be as identical as regards susceptibility as two samples of one and the same mutton-infusion. Experiments with other trays are described in the full account of this investigation, and calculations are made which prove the error of the assertion that the germs are but scantily distributed through the air. There are billions of them in every ordinary London room.

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[1] In hospital practice the opening of a wound during the passage of a Bacterial cloud would have an effect very different from the opening of it in the interspace between two clouds. Certain caprices in the behaviour of dressed wounds may possibly be accounted for in this way.

Under the heading 'Nothing New under the Sun,' Professor Huxley has just sent me the following remarkable extract:—'Uebrigens kann man sich die in der Atmosphäre schwimmenden Thierchen wie Wolken denken, mit denen ganz leere Luftmassen, ja ganze Tage völlig reinen Luftverhältnisse wechseln.' (Ehrenberg, 'Infusions Thierchen,' 1838, p. 525.) The coincidence of phraseology is surprising, for I knew nothing of Ehrenberg's conception. My 'clouds,' however, are but small miniatures of his.

The parallelism of these actions with the progress of infectious disease may be traced still further. The 'Times' of January 17 contained a letter on typhoid fever, signed 'M.D.,' in which occurred the following remarkable statement: 'In one part of it [Edinburgh], congregated together and inhabited by the lowest of the population, there are, according to the Corporation return for 1874, no less than 14,319 houses or dwellings—many under one roof, on the 'flat' system—in which there are no house connections whatever with the street sewers, and, consequently, no water-closets. To this day, therefore, all the excrementitious and other refuse of the inhabitants is collected in pails or pans, and remains in their midst, generally in a partitioned-off corner of the living-room, until the next day, when it is taken down to the streets and emptied into the Corporation carts. Drunken and vicious though the population be, herded together like sheep, and with the filth collected and kept for twenty-four hours in their very midst, it is a remarkable fact that typhoid fever and diphtheria are simply unknown in these wretched hovels.'

This case has its analogue in the following experiment, which is representative of a class: On November 30 a quantity of animal refuse, embracing beef, fish, rabbit, hare, was placed in two large test-tubes opening into a protecting-chamber containing six tubes. On December 13, when the refuse was in a state of noisome putrefaction, infusions of whiting, turnip, beef, and mutton were placed in the other four tubes. They were boiled and abandoned to the action of the foul 'sewer-gas' emitted by their two putrid companions. On Christmas-day these four infusions were limpid. The end of the pipette was then dipped into one of the putrid tubes, and a quantity of matter, comparable in smallness to the pock-lymph, held on the point of a lancet, was transferred to the turnip. Its clearness was not sensibly affected at the time; but on the following day it was turbid throughout. On the 27th a speck from the infected turnip was transferred to the whiting; on the 28th disease had taken entire possession of the whiting. To the present hour the beef- and mutton-tubes remain as limpid as distilled water. Just as in the case of the living men and women in Edinburgh, no amount of fetid gas had the power of propagating the plague as long as the organisms which constitute the true contagium did not gain access to the infusions.

The universal prevalence of the germinal matter of *Bacteria* in water has been demonstrated with the utmost evidence by the experiments of Dr. Burdon Sanderson. But the germs in water are in a very different condition, as regards readiness for development, from those in air. In water they are thoroughly wetted, and ready, under the proper conditions, to pass rapidly into the finished organism. In air they are more or less desiccated, and require a period of preparation more or less long to bring them up to the starting-point of the water-germs. The rapidity of development in an infusion infected by either a speck of liquid containing *Bacteria* or a drop of water is extraordinary. On January 4 a thread of glass almost as fine as a hair was dipped into a cloudy turnip-infusion, and the tip only of the glass fibre was introduced into a large test-tube containing an infusion of red mullet. Twelve hours subsequently the perfectly pellucid liquid was cloudy throughout. A second test-tube containing the same infusion was infected with a single drop of the distilled water furnished by Messrs. Hopkin and Williams; twelve hours also sufficed to cloud the infusion thus treated. Precisely the same experiments were made with herring with the same result. At this season of the year several days' exposure to the air is needed to produce the same effect. On December 31 a strong turnip-infusion was prepared by digesting in distilled water at a temperature of 120° Fahr. The infusion was divided between four large test-tubes, in one of which it was left unboiled, in another boiled for five minutes, and in the two remaining ones boiled, and, after cooling, infected with one drop of beef-infusion containing *Bacteria*. In twenty-four hours the unboiled tube and the two infected ones were cloudy, the unboiled tube being the most turbid of the three. The infusion here was peculiarly limpid after digestion; for turnip it was quite exceptional, and no amount of searching with the microscope sufficed to reveal in it, at first, the trace of a living Bacterium; still germs were there which, suitably nourished, passed in a single day into Bacterial swarms without number.[1] Five days did not suffice to produce an effect approximately equal to this in the boiled tube, which was uninfected but exposed to the common laboratory air.

There cannot, moreover, be a doubt that the germs in the air differ widely among themselves as regards *preparedness* for development. Some are fresh, others old; some are dry, others moist. Infected by such germs, the same infusion would require different lengths of time to develop Bacterial life. This remark applies to and probably explains the different degrees of rapidity with which epidemic disease acts upon different people. In some the hatching-period, if it may be called such, is long, in some short, the differences depending upon the different degrees of preparedness of the contagium.

Such is an outline of the present enquiry as far as it is now complete. It gives me pleasure to refer to the untiring patience, the admirable mechanical skill, the veracity in thought, word, and deed displayed throughout by my assistant, Mr. John Cottrell, who was zealously aided by his junior colleague, Mr. Frank Valter.

MY interest in the question of spontaneous generation was first excited by the imperishable investigations of Pasteur, while the medical bearings of the question were subsequently made more and more clear to me, mainly, I ought to say, by the writings and conversation of Dr. William Budd. For more than fifteen years this strong and original thinker fought in England an up-hill fight in favour of the germ theory of epidemic disease,[1] and his last intellectual effort, the production of his great work on Typhoid Fever, under which, unhappily, his over-active mind gave way, consisted in conclusively demonstrating both the contagious character and the seat of the contagium of that disease. The quotation from a letter given at page 172 of this volume will show the clearness and definiteness with which Dr. Budd from the first grasped the doctrine of 'the vitality of contagia' which is now everywhere gaining ground.

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[1] The germs are to be found in the heart of the clearest blocks of Norway ice. Such water prepared by myself has been examined by Dr. *Sanderson*, and found to be quite as infectious as ordinary water.

Since the time here referred to, able investigators in various European countries have taken up the question of contagium, until at the present moment no other medical principle occupies so much thought, or is the subject of so much discussion. 'How does it happen,' says Dr. Burdon Sanderson,[2] 'that these *Bacteria*, which we suppose must have existed half-a-dozen years ago in as great numbers as at present, were then scarcely heard of, and that they now occupy so large a place in the medical literature of this country and of Germany, and have lately afforded material for lively discussion in the French Academy?' Dr. Sanderson points out the relation of Lister in England and of Hallier in Germany to the movement regarding *Bacteria* which is now working like a ferment through the medical world. But to scarcely any other workers are we more indebted than to Dr. Sanderson and his colleagues, for the continued and successful prosecution of researches bearing upon the pathology of contagion.

I, this year, took with me to the Alps the excellent reports of the medical officer of the Privy Council, together with the associated memoirs of Dr. Sanderson and Dr. Klein. On the healthy mountain sides, in the intervals of other work, I read these papers, with the interest of one who saw in them the steady growth and consolidation of a principle which promises to rescue medicine from the reproach of empiricism, to raise it to the rank of a true science, and to place those 'invisible foes,' as they have been called by the celebrated Cohn, which lurk in the air we breathe and in the water we drink, within the grasp of the physician.

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[1] Supported, I am happy to say, by one eminent authority, Sir Thomas Watson.

[2] 'British Medical Journal.' January 16, 1875.

A few extracts from the reports with which Mr. John Simon prefaces the memoirs of the gentlemen who work in his department, will show what important advances have been made of late years in our knowledge of the contagia of infective disease. 'Ten years ago,' says Mr. Simon, in his report to the Privy Council for 1874, 'we had not even a beginning of any true insight into the respective contagia which excite acute infective diseases; and, considering the large and lasting interest which exact studies in this field of scientific research must have for the human race, I think the fact noteworthy that the first of such studies were instituted and the first steps of discovery made with reference to a contagious fever of horned cattle. I refer, namely, to the researches which were made under Her Majesty's Government in 1865, in aid of the then Cattle-plague Commission; when Dr. Beale, working at the microscopy of the disease, drew attention to the swarms of extremely minute particles which he found universally present in the textures and juices of the animals, and which he believed to be the contagium of the disease; and when Dr. Sanderson, working at the matter from a different point of view, succeeded in showing experimentally that the true contagium admits of being physically distinguished in the animal juices which contain it, and of being so separated from them as to leave them without infective power. In the next succeeding years the writings of Dr. Hallier, Professor of Botany in Jena, brought under animated discussion, as a branch of microphytology, the nature and origin of contagium particles in a great variety of diseases, human and brute. New experimental knowledge of several contagia was set forth in the writings of Professor Chauveau, of the Veterinary School of Lyons, and in 1870 I had the honour of presenting Dr. Sanderson's first report of researches made in the matter. At that time general conclusions seemed justified, first, that the characteristic-shaped elements which the microscope had shown abounding in various infective products *are self-multiplying organic forms*, not congeneric with the animal body in which they are found, but apparently of the lowest vegetable kind; and secondly, that such living organisms are probably the essence, or an inseparable part of the essence, of all contagia of disease. The study of morbid contagion was thus brought into seeming affinity with that which had for some years before been made by Professor Schroeder and M. Pasteur in the ordinary processes of fermentation and putrefaction; and there began to be faintly visible to us a vast destructive laboratory of Nature, wherein the diseases which are most fatal to animal life, and the changes to which dead organic matter is passively liable, appear bound together by what must at least be called a very close analogy of causation. This view of the matter has since then become greatly more distinct, in consequence of the investigations made by Dr. Sanderson, particularly in 1871 and 1872, with reference to the common septic contagium or ferment. For in that ferment there seems now to be identified a force which, acting disintegratively upon organic matter, whether *dead or living*, can on the one hand initiate putrefaction of what is dead, and on the other hand initiate febrile and inflammatory processes in what is living.

'Continuation of this line of study in regard of acute infections of the living body, is represented in the first two of the appended papers.

'In the first paper Dr. Sanderson brings down to the present time an account of the microphytes of contagion, setting forth more particularly such positive knowledge as had yet been obtained with regard to the respective contagia and respective morbid processes of diphtheria, erysipelas, relapsing fever, and splenic fever, or the "milzbrand" of veterinary practice.

'The second paper represents a contribution to the growing modern doctrine of contagion in an exposition by Dr. Klein of the intimate nature of the local changes which characterise the acute zymotic disease known as *Variola Ovina* or *Sheep-pox*. Dr. Klein has been able to identify the contagium particles of that infectious fever as definite microphytes growing and fructifying with vast rapidity in the canals and tissues of the infected skin. The woodcuts of his annexed paper show the process to have been observed by him with a completeness not yet, I believe, attained in regard of any other such case. And these results of his, while they complete, as regards the special disease in question, the broad pathological outline which previous inductions had rendered probable, must also, I think, be regarded as tending very importantly to confirm, while they illustrate, the general doctrine *of the vitality of contagia*.'

It was with no levity of mind that I, an outsider, who had been drawn by my own experiments in 1868–69 to the contemplation of the subject, ventured to range myself on the side of those who then advocated the doctrine so clearly enunciated by Mr. Simon, and so vastly strengthened by the researches conducted under his direction. What was then more or less the surmise of men of genius like William Budd, is now being raised to the level of demonstration. With increased discipline investigation naturally tends to become more detailed and specific, the forecasts of the scientific imagination becoming gradually displaced by the solid matter of fact. Speaking of the havoc produced by typhoid fever and of the contagion to which that fever is due, Dr. Budd, in his celebrated work,[1] observes: 'It is humiliating to think that issues such as these should be contingent on the powers of an agent so low in the scale of being that the mildew which springs up on decaying wood must be considered high in comparison.'

In his last report to the Privy Council Mr. Simon was able to announce the probable discovery by Dr. Klein of the agent here referred to. After passing in review two important papers by Professor Burdon Sanderson on the 'Process of Fever,' and on the 'Experimental Study of Infective Inflammations,' Mr. Simon thus refers to Dr. Klein's paper: 'The third paper, which is by Dr. Klein, gives (as foreshadowed in my last report) the extremely interesting results of his investigation of the intimate anatomy of *Enteric Fever*; and Dr. Klein, who fortunately is artist enough to reproduce admirably with his pencil the anatomical appearances which he displays under the microscope, has here, as on former occasions, illustrated his written report with drawings which make the results peculiarly clear.

'The paper has its distinctive and very great interest in the fact that it purports to describe for the first time the contagium of enteric fever as something cognisable to the eye: in respect of certain multiplying microscopical forms, apparently of the lowest vegetable life, which are found in innumerable swarms in the bowel-textures and bowel-discharges of the sick; penetrating from the former to diffuse throughout the patient's general system,[1] and teeming in the latter to represent, as this view supposes, the possible germs of epidemic infection.

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[1] 'Typhoid Fever; its Nature, Mode of Spreading and Prevention.' *Longmans, 1873, p. 4.*

'The most cursory glance cast by the anatomist at the illustrations of Dr. Klein's paper will convince him of the reality of the facts which Dr. Klein interprets to the above effect: and that the interpretation thus assigned to the facts is the one which they must generally receive is, I think, an inevitable consequence of the considerations which were stated in my last report with general regard to agencies of contagion. The enteric fever of man is not yet known to be communicable to any other animal; and it has therefore not been possible to perform in relation to its supposed contagium such experiments as have been made on the lower animals with respect to the contagia of some other diseases. In absence of such experiments, the same degree of certainty cannot at present be expressed with regard to the contagium of enteric fever as with regard to that (for instance) of sheep-pox: but, subject to any correction which experiment may hereafter supply, we may at least accept as approximately proven, that the contagium of enteric fever has its essence, or part of its essence, in the microphyte which Dr. Klein has discovered; and that here accordingly is a further illustration of the general doctrine which I have noticed on many previous occasions, with regard to the significance of specific organic forms in the constitution of specific contagia.

In an immediately practical point of view, much interest attaches to Dr. Klein's remark that the microphyte, which he describes in the present paper, closely corresponds with that which Professor Cohn, the eminent micro-botanist, described, under the name of Crenothrix polyspora, as found by him "in the well-water of a certain district in Breslau, famous for the frequent occurrence of enteric fever among its inhabitants."'

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[1] This reminds one of the spread of *Pebrine* through the silkworms experimented on by Pasteur. In the case of the worms the organisms first took possession of the intestinal canal, and spread thence throughout the body of the worm. See p. 135 of this volume.

Rarely has the pen of a medical writer produced a paragraph of equal importance to that wherein Mr. Simon draws a distinction between the fœtid gases and stinks arising from animal and vegetable putrefaction, and the real contagia concerned in the production and propagation of typhoid fever. 'An important suggestion,' he writes, 'of modern science, with regard to the nature of the operations by which filth, attacking the human body, is able to disorder or destroy it, is, that the chief morbific agencies in filth are other than those chemically-identified stinking gaseous products of organic decomposition which force themselves on popular attention.[1] Exposure to the sufficiently-concentrated forms of organic decomposition (as, for instance, in an unventilated old cesspool or long-blocked sewer) may, no doubt, prove immediately fatal, by reason of some large quantity of sulphide of ammonium, or other like poisonous and fœtid gas, which the sufferer suddenly inhales; and far smaller doses of these fœtid gases as breathed with extreme dilution in ordinary stinking atmospheres, both give immediate headache and general discomfort to sensitive persons temporarily exposed to them, and also appear to keep in a somewhat vaguely depressed state of health many who habitually breathe them: but here, so far as we yet know, is the end of the potency of these stinking gases. While, however, thus far there is only the familiar case of the so-called *common chemical poison*, which hurts by instant action and in direct proportion to its palpable and ponderable dose, the other and far wider possibilities of mischief which we recognise in filth are such as apparently must be attributed to *morbific ferments* or *contagia*; matters which not only are not gaseous, but, on the contrary, so far as we know them, seem to have their essence, or an inseparable part of it, in certain solid elements which the microscope discovers in them, in living organisms, namely, which in their largest sizes are but very minute microscopical objects, and at their least sizes are probably unseen even with the microscope; organisms which, in virtue of their vitality, are indefinitely self-multiplying within their respective spheres of operation, and which, therefore, as in contrast with common poisons, can develop indefinitely large ulterior effects from first doses, which are indefinitely small.[1]

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[1] Six years ago I wrote thus: 'Drains and cesspools, indeed, are by no means in such evil odour as they used to be. A fœtid Thames and a low death-rate occur from time to time in London. For, if the special matter or germs of epidemic disorder be not present, a corrupt atmosphere, however obnoxious otherwise, will not produce the disorder.' See p. 144 of this volume.

'Of ferments thus characterised, the apparently essential factors of specific chemical processes, at least one sort—the ordinary septic ferment—seems always to be present where putrefactive changes are in progress, as of course in all decaying animal refuse; while others, though certainly not essential to all such putridity, are in different degrees apt, and some of them little less than certain, to be frequent incidents of our ordinary refuse. As, apparently, it is by these various agencies (essential and incidental) that filth produces "zymotic" disease, it is important not to confound them with the fœtid gases of organic decomposition; and the question, what infecting powers are prevalent in given atmospheres should never be regarded as a mere question of stink. It is of the utmost practical importance to recognise in regard of filth, that agents which destroy its stink may yet leave all its main powers of disease-production undiminished. Whether the ferments of disease, if they could be isolated in sufficient quantity, would prove themselves in any degree odorous, is a point on which no guess need be hazarded; but it is certain that in doses in which they can fatally infect the human body they are infinitely out of reach of even the most cultivated sense of smell, and that this sense (though its positive warnings are of indispensable sanitary service) is not able, except by indirect and quite insufficient perceptions, to warn us against risks of morbid infections.

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[1] See the parallel case of the infection of infusions in the first article of this volume, p. [23. For an illustration of the power of self-multiplication in silkworms, see p. 139. See also Lister, p. 148; also pp. 171, 173.

'Even as regards the positive notices which we receive by the sense of smell with regard to putrefactive decomposition, we must not assume that the diffusion and potency of septic ferment in the air necessarily go *pari passu* with the diffusion and offensiveness of the fœtid gases. Witness, on a very large scale, the experience of London in the summer of 1858; when, as persons who were then frequenting Westminster may well remember, our tidal river, enormously charged with decomposing sewage, stank week after week in a degree which excited much public alarm as to the possible consequences of the nuisance, and even led to an immediate interference of the Legislature; but when, though the quantity of sulphuretted hydrogen in the river atmosphere was such as rapidly to blacken the ordinary chemical test-papers, as well as to affect in the same way the lead-paint of vessels on the river, and was enough also to produce among persons much engaged on the river such signs of sulphide-poisoning as I have above mentioned, the particular ailments which attest the working of septic ferment *on the human body* were in even less than average prevalence among the unwilling subjects of this large experiment.'

At page 172 of these 'Fragments' I use the following language: It has been said, and it is sure to be repeated, that I am quitting my *métier* in speaking of these things. Not so. I am dealing with questions on which minds accustomed to weigh the value of experimental evidence are alone competent to decide, and regarding which minds so trained are as capable of forming a correct opinion as they are regarding a problem of magnetism, or of radiant heat. 'The germ theory of disease,' it has been said, 'appertains to the biologist and the physician:' granted; but not to them alone; for where is the biologist or physician whose researches in connection with this subject could for one instant be compared to those of the chemist Pasteur? It is not the philosophic members of the medical profession who are likely to be dull to the reception of truth because it does not originate within the pale of the profession itself.

It was Dr. Bastian who claimed in the words above quoted the germ theory of disease as the property of the biologist and the physician. For six years his claim has been conceded to him, and we now see the use he has made of the concession. But I regret to say, that the same view of the subject has been taken by other very distinguished men. Sir William Jenner, for example, in his address as President of the Clinical Society, employs the following language: 'I do not say, nor do I think, that the arguments and facts able to be adduced in favour of the origin *de novo* of the contagious diseases are conclusive; but I do say they are strong enough to make us pause before we accept the theory advocated by Dr. Wm. Budd, and to which Professor Tyndall has lent the weight of his name—a weight which would, however, be greater on the point in question if he had himself studied the subject on which he has, I am sorry to say, addressed the public in a strain calculated to check unprejudiced individual enquiry.'

The courtesy of Sir William Jenner's reference encourages me to hope that he will accept my assurance that the part I have publicly taken in reference to Dr. Budd was preceded by no small amount of study of the question in hand. Dr. Murchison, the most prominent leader of the party in the medical profession who teach the spontaneous generation of infective diseases, affirms that the contagium of typhoid fever 'may be generated independently of a previous case by fermentation of fæcal and perhaps other forms of organic matter.' I think it probable that the experience of Sir William Jenner, or of Dr. Murchison, in regard to fæcal matter, is less than my own. For more than twenty years I have annually had occasion to observe fæcal matter of all kinds seething under a summer sun in the villages, hamlets, and châlets of Switzerland, and proving itself utterly incapable of generating that contagium which, according to Dr. Murchison's teaching, is a product of its fermentation. There is but one way of getting over the arguments of Dr. Budd, and that is—to destroy his facts: for these being granted, his conclusions are irresistible. To his facts and reasonings are now to be added the whole weight of the researches conducted under the auspices of the Privy Council. These are dead against the notion favoured by Sir William Jenner, and enunciated by Dr. Murchison as one of the leading conclusions in the summary of his learned work on 'Typhoid Fever.' I may be permitted to express a doubt whether in England a dozen years hence a single physician of their commanding eminence will be found endorsing the views which they have thought it their duty to enunciate and defend.

At the end of this volume will be found, with a few omissions immaterial to the principle discussed, the letter to the 'Times' which provoked at the time of its publication so much hostile criticism, and brought down upon me the censure of Dr. Murchison and Sir William Jenner. I commit it, without misgiving, to the judgment of the future. In reference to my allusion to Dr. Klein, Dr. Murchison, at a meeting of the Pathological Society on May 4, 1875, spoke thus: 'I believe that Dr. Sanderson himself would be the first to repudiate any such statement, and I think that any one who has listened to this debate must be satisfied that such an announcement was entirely unwarranted by Dr. Klein's discovery of *Bacteria* in connection with the lesions of enteric fever.' The reader must judge between Dr. Murchison and me. The warrant for my reference is to be found at pp. [29, [30, and [31, where Mr. Simon's account of Dr. Klein's discovery is given verbatim.

I take this opportunity of notifying my acceptance of a correction on a point of history at the hands of my eminent opponent the Reverend James Martineau. It has reference to a passage in the 'Belfast Address,' in which the relationship of Empedocles to Democritus is mentioned. Speaking of a passage from Lange, Mr. Martineau says: 'Misled by the order of this passage, which gives the missing thought after naming the gap which it might have filled, Dr. Tyndall has described Empedocles as intentionally making good a defect in Democritus. This is an inversion of the chronology. Empedocles preceded Democritus by at least a generation, being born about B.C. 490 and dying B.C. 430, whilst Democritus, whom we find at Thurii, shortly after the foundation of the colony, in B.C. 443, died at a very advanced age B.C. 357.' A reference to dates in Smith's 'Classical Dictionary' will show that my mistake was not an unnatural one.

PART I.

I.

THE CONSTITUTION OF NATURE.[1]

1865.

WE cannot think of space as finite, for wherever in imagination we erect a boundary, we are compelled to think of space as existing beyond it. Thus by the incessant dissolution of limits we arrive at a more or less adequate idea of the infinity of space. But, though compelled to think of space as unbounded, there is no mental necessity compelling us to think of it either as filled or empty; whether it is so or not must be decided by experiment and observation. That it is not entirely void, the starry heavens declare; but the question still remains, Are the stars themselves hung in vacuo? Are the vast regions which surround them, and across which their light is propagated, absolutely empty? A century ago the answer to this question would have been, 'No, for particles of light are incessantly shot through space.' The reply of modern science is also negative, but on different grounds. It has the best possible reasons for rejecting the idea of luminiferous particles; but, in support of the conclusion that the celestial spaces are occupied by matter, it is able to offer proofs almost as cogent as those which can be adduced for the existence of an atmosphere round the earth. Men's minds, indeed, rose to a conception of the celestial and universal atmosphere through the study of the terrestrial and local one. From the phenomena of sound, as displayed in the air, they ascended to the phenomena of light, as displayed in the *aether*; which is the name given to the interstellar medium.

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[1] '*Fortnightly Review,*' vol. iii. p. 129.

The notion of this medium must not be considered as a vague or fanciful conception on the part of scientific men. Of its reality most of them are as convinced as they are of the existence of the sun and moon. The luminiferous aether has definite mechanical properties. It is almost infinitely more attenuated than any known gas, but its properties are those of a solid rather than of a gas. It resembles jelly rather than air. A body thus constituted may have its boundaries; but, although the aether may not be co-extensive with space, it must at all events extend as far as the most distant visible stars. In fact it is the vehicle of their light, and without it they could not be seen. This all-pervading substance takes up their molecular tremors, and conveys them with inconceivable rapidity to our organs of vision. It is the transported shiver of bodies countless millions of miles distant, which translates itself in human consciousness into the splendour of the firmament at night.

If the aether have a boundary, masses of ponderable matter might be conceived to exist beyond it, but they could emit no light. Beyond the aether dark suns might burn; there, under proper conditions, combustion might be carried on; fuel might consume unseen, and metals be fused in invisible fires. A body, moreover, once heated there, would continue for ever heated; a sun or planet once molten, would continue for ever molten. For, the loss of heat being simply the abstraction of molecular motion by the aether, where this medium is absent no cooling could occur. A sentient being on approaching a heated body in this region, would be conscious of no augmentation of temperature. The gradations of warmth dependent on the laws of radiation would not exist, and actual contact would first reveal the heat of an extra aethereal sun.

Imagine a paddle-wheel placed in water and caused to rotate. From it, as a centre, waves would issue in all directions, and a wader as he approached the place of disturbance would be met by stronger and stronger waves. This gradual augmentation of the impression made upon the wader's body is exactly analogous to the augmentation of light when we approach a luminous source. In the one case, however, the coarse common nerves of the body suffice; for the other we must have the finer optic nerve. But suppose the water withdrawn; the action at a distance would then cease, and, as far as the sense of touch is concerned, the wader would be first rendered conscious of the motion of the wheel by the blow of the paddles. The transference of motion from the paddles to the water is mechanically similar to the transference of molecular motion from the heated body to the aether; and the propagation of waves through the liquid is mechanically similar to the propagation of light and radiant heat.

As far as our knowledge of space extends, we are to conceive it as the holder of the luminiferous aether, through which are interspersed, at enormous distances apart, the ponderous nuclei of the stars. Associated with the star that most concerns us we have a group of dark planetary masses revolving at various distances round it, each again rotating on its own axis; and, finally, associated with some of these planets we have dark bodies of minor note—the moons. Whether the other fixed stars have similar planetary companions or not is to us a matter of pure conjecture, which may or may not enter into our conception of the universe. But probably every thoughtful person believes, with regard to those distant suns, that there is, in space, something besides our system on which they shine.

From this general view of the present condition of space, and of the bodies contained in it, we pass to the enquiry whether things were so created at the beginning. Was space furnished at once, by the fiat of Omnipotence, with these burning orbs? To this question the man of science, if he confine himself within his own limits, will give no answer. It must, however, be remarked that in the formation of an opinion he has better materials to guide him than anybody else. He can clearly show that the present state of things *may* be derivative. He can even assign reasons which render probable its derivative origin—that it was not originally what it now is. At all events, he can prove that out of common non-luminous matter this whole pomp of stars might have been evolved.

The law of gravitation enunciated by Newton is, that every particle of matter in the universe attracts every other particle with a force which diminishes as the square of the distance increases. Thus the sun and the earth mutually pull each other; thus the earth and the moon are kept in company; the force which holds every respective pair of masses together being the integrated force of their component parts. Under the operation of this force a stone falls to the ground and is warmed by the shock; under its operation meteors plunge into our atmosphere and rise to incandescence. Showers of such doubtless fall incessantly upon the sun. Acted on by this force, were it stopped in its orbit to-morrow, the earth would rush towards, and finally combine with, the sun. Heat would also be developed by this collision, and Mayer, Helmholtz, and Thomson have calculated its amount. It would equal that produced by the combustion of more than 5,000 worlds of solid coal, all this heat being generated at the instant of collision. In the attraction of gravity, therefore, acting upon non-luminous matter, we have a source of heat more powerful than could be derived from any terrestrial combustion. And were the matter of the universe thrown in cold detached fragments into space, and there abandoned to the mutual gravitation of its own parts, the collision of the fragments would in the end produce the fires of the stars.

The action of gravity upon matter originally cold may, in fact, be the origin of *all* light and heat, and also the proximate source of such other powers as are generated by light and heat. But we have now to enquire what is the light and what is the heat thus produced? This question has already been answered in a general way. Both light and heat are modes of motion. Two planets clash and come to rest; their motion, considered as that of masses, is destroyed, but it is really continued as a motion of their ultimate particles. It is this latter motion, taken up by the aether, and propagated through it with a velocity of 186,000 miles a second, that comes to us as the light and heat of suns and stars. The atoms of a hot body swing with inconceivable rapidity; but this power of vibration necessarily implies the operation of forces between the atoms themselves. It reveals to us that while they are held together by one force, they are kept asunder by another, their position at any moment depending on the equilibrium of attraction and repulsion. The atoms are virtually connected by elastic springs, which oppose at the same time their approach and their retreat, but which tolerate the vibration called heat. The molecular vibration once set up is instantly shared with the aether, and diffused by it throughout space.

We on the earth's surface live night and day in the midst of *aethereal commotion.* The medium is never still.

The cloud canopy above us may be thick enough to shut out the light of the stars; but this canopy is itself a warm body, which radiates its motion through the aether. The earth also is warm, and sends its heat-pulses incessantly forth. It is the waste of its molecular motion in space that chills the earth upon a clear night; it is the return of its motion from the clouds which prevents the earth's temperature, on a cloudy night, from falling so low. To the conception of space being filled, we must therefore add the conception of its being in a state of incessant tremor.

The sources of this vibration are the ponderable masses of the universe. Let us take a sample of these and examine it in detail. When we look to our planet, we find it to be an aggregate of solids, liquids, and gases. When we look at any one of these, we generally find it composed of still more elementary parts. We learn, for example, that the water of our rivers is formed by the union, in definite proportions, of two gases, oxygen and hydrogen. We know how to bring these constituents together, so as to form water: we also know how to analyse the water, and recover from it its two constituents. So, likewise, as regards the solid proportions of the earth. Our chalk hills, for example, are formed by a combination of carbon, oxygen, and calcium. These are elements the union of which, in definite proportions, has resulted in the formation of chalk. The flints within the chalk we know to be a compound of oxygen and silicium, called silica; and our ordinary clay is, for the most part, formed by the union of silicium, oxygen, and the well-known light metal, aluminium. By far the greater portion of the earth's crust is compounded of the elementary substances mentioned in these few lines.

The principle of gravitation has been already described as an attraction which every particle of matter, however small, has for every other particle. With gravity there is no selection; no particular atoms choose, by preference, other particular atoms as objects of attraction; the attraction of gravitation is proportional to the quantity of the attracting matter, regardless of its quality. But in the molecular world which we have now entered matters are otherwise arranged. Here we have atoms between which a strong attraction is exercised, and also atoms between which a weak attraction is exercised. One atom can jostle another out of its place, in virtue of a superior force of attraction. But, though the amount of force exerted varies thus from atom to atom, it is still an attraction of the same mechanical quality, if I may use the term, as that of gravity itself. Its intensity might be measured in the same way, namely, by the amount of motion which it can generate in a certain time. Thus the attraction of gravity at the earth's surface is expressed by the number 32; because, when acting freely on a body for a second of time, it imparts to the body a velocity of thirty-two feet a second. In like manner the mutual attraction of oxygen and hydrogen might be measured by the velocity imparted to the atoms in their rushing together. Of course, such a unit of time as a second is not here to be thought of, the whole interval required by the atoms to cross the minute spaces which separate them not amounting probably to more than an inconceivably small fraction of a second.

It has been stated that when a body falls to the earth it is warmed by the shock. Here we have what we may call a *mechanical* combination of the earth and the body. Let us suffer the falling body and the earth to dwindle in imagination to the size of atoms, and for the attraction of gravity let us substitute that of chemical affinity; we have then what is called a *chemical* combination. The effect of the union in this case also is the development of heat, and from the amount of heat generated we can infer the intensity of the atomic pull. Measured by ordinary mechanical standards, this is enormous. Mix eight pounds of oxygen with one of hydrogen, and pass a spark through the mixture; the gases instantly combine, their atoms rushing over the little distances between them. Take a weight of 47,000 pounds to an elevation of 1,000 feet above the earth's surface, and let it fall; the energy with which it will strike the earth will not exceed that of the eight pounds of oxygen atoms, as they dash against one pound of hydrogen atoms to form water.

It is sometimes stated that gravity is distinguished from all other forces by the fact of its resisting conversion into other forms of force. Chemical affinity, it is said, can be converted into heat and light, and these again into magnetism and electricity: but gravity refuses to be so converted; being a force maintaining itself under all circumstances, and not capable of disappearing to give place to another. If by this be meant that a particle of matter can never be deprived of its weight, the assertion is correct; but the law which affirms the convertibility of natural forces was never intended, in the minds of those who understood it, to affirm that such a conversion as that here implied occurs in any case whatever. As regards convertibility into heat, gravity and chemical affinity stand on precisely the same footing. The *attraction* in the one case is as indestructible as in the other. Nobody affirms that when a stone rests upon the surface of the earth, the mutual attraction of the earth and stone is abolished; nobody means to affirm that the mutual attraction of oxygen for hydrogen ceases, after the atoms have combined to form water. What is meant, in the case of chemical affinity, is, that the pull of that affinity, acting through a certain space, imparts a motion of translation of the one atom towards the other. This motion is *not* heat, nor is the force that produces it heat. But when the atoms strike and recoil, the motion of translation is converted into a motion of vibration, which *is* heat. The vibration, however, so far from causing the extinction of the original attraction, is in part carried on by that attraction. The atoms recoil, in virtue of the elastic force which opposes actual contact, and in the recoil they are driven too far back. The original attraction then triumphs over the force of recoil, and urges the atoms once more together. Thus, like a pendulum, they oscillate, until their motion is imparted to the surrounding aether; or, in other words, until their heat becomes *radiant* heat.

In this sense, and in this sense only, is chemical affinity converted into heat. There is, first of all, the attraction between the atoms; there is, secondly, *space* between them. Across this space the attraction urges them. They collide, they recoil, they oscillate. There is here a change in the form of the motion, but there is no real loss. It is so with the attraction of gravity. To produce motion by gravity space must also intervene between the attracting bodies: when they strike together motion is apparently destroyed, but in reality there is no destruction. Their atoms are suddenly urged together by the shock; by their own perfect elasticity these atoms recoil; and thus is set up the molecular oscillation which announces itself to the nerves as heat.

It was formerly universally supposed that by the collision of unelastic bodies force was destroyed. Men saw, for example, that when two spheres of clay, painter's putty, or lead, were urged together, the motion possessed by the masses, prior to impact, was more or less annihilated. They believed in an absolute destruction of the force of impact. Until recent times, indeed, no difficulty was experienced in believing this, whereas, at present, the ideas of force and its destruction refuse to be united in most philosophic minds. In the collision of elastic bodies, on the contrary, it was observed that the motion with which they clashed together was in great part restored by the resiliency of the masses, the more perfect the elasticity the more complete being the restitution. This led to the idea of perfectly elastic bodies—bodies competent to restore by their recoil the whole of the motion which they possessed before impact.

Hence arose the idea of the *conservation* of force, as opposed to that destruction of force which was supposed to occur when unelastic bodies met in collision.

We now know that the principle of conservation holds equally good with elastic and unelastic bodies. Perfectly elastic bodies develop *no heat* on collision. They retain their motion afterwards, though its direction may be changed; and it is only when sensible motion is wholly or partly destroyed, that heat is generated. This always occurs in unelastic collision, the heat developed being the exact equivalent of the sensible motion extinguished. This heat virtually declares that the property of elasticity, denied to the masses, exists among their atoms; and by the recoil and oscillation of these the principle of conservation is vindicated.

But ambiguity in the use of the term 'force' has been for some time more and more making itself felt. We called the attraction of gravity a force, without any reference to motion. A body resting on a shelf is as much pulled by gravity as when, after having been pushed off the shelf, it falls towards the earth. We applied the term force also to that molecular attraction which we called chemical affinity. When, however, we spoke of the conservation of force, in the case of elastic collision, we meant neither a pull nor a push, which, as just indicated, might be exerted upon inert matter, but we meant the *moving force*, if I may use the term, of the colliding masses.

What I have called moving force has a definite mechanical measure, in the amount of work that it can perform. The simplest form of work is the raising of a weight. A man walking up-hill, or up-stairs, with a pound weight in his hand, to an elevation say of sixteen feet, performs a certain amount of work, over and above the lifting of his own body. If he ascend to a height of thirty-two feet, he does twice the work; if to a height of forty-eight feet, he does three times the work; if to sixty-four feet he does four times the work, and so on. If, moreover, he carries up two pounds instead of one, other things being equal, he does twice the work; if three, four, or five pounds, he does three, four, or five times the work. In fact it is plain that the work performed depends on two factors, the weight raised and the height to which it is raised. It is expressed by the product of these two factors.

But a body may be caused to reach a certain elevation in opposition to the force of gravity, without being actually carried up to that elevation. If a hodman, for example, wished to land a brick at an elevation of sixteen feet above the place where he stood, he would probably pitch it up to the bricklayer. He would thus impart, by a sudden effort, a velocity to the brick sufficient to raise it to the required height; the work accomplished by that effort being precisely the same as if he had slowly carried up the brick. The initial velocity to be imparted, in this case, is well known. To reach a height of sixteen feet, the brick must quit the man's hand with a velocity of thirty-two feet a second. It is needless to say, that a body starting with any velocity, would, if wholly unopposed or unaided, continue to move *for ever* with the same velocity. But when, as in the case before us, the body is thrown upwards, it moves in opposition to gravity, which incessantly retards its motion, and finally brings it to rest at an elevation of sixteen feet. If not here caught by the bricklayer, it would return to the hodman with an accelerated motion, and reach his hand with the precise velocity it possessed on quitting it.

Supposing the man competent to impart to the brick, at starting, a speed of sixty-four feet a second, or twice its former speed, would the amount of work performed in this effort be only twice what it was in the first instance? No; it would be four times that quantity. A body starting with twice the velocity of another, will rise to four times the height; in like manner, a three-fold velocity will give a nine-fold elevation, a four-fold velocity will give a sixteen-fold elevation, and so on. The height attained, then, or the work done, is not proportional to the velocity, but to the *square* of the velocity. As before, the work is also proportional to the weight elevated. Hence the work which any moving mass whatever is competent to perform, by the motion which it at any moment possesses, is jointly proportional to its weight and the square of its velocity. Here, then, we have a second measure of work, in which we simply translate the idea of height into its equivalent idea of motion.

In mechanics, the product of the mass of a moving body into the square of its velocity, expresses what is called the *vis viva*, or living force. It is also sometimes called the 'mechanical effect.' If, for example, a cannon pointed to the zenith urge a ball upwards with twice the velocity imparted to a second ball, the former will rise to four times the height attained by the latter. If directed against a target, it will also do four times the execution. Hence the importance of imparting a high velocity to projectiles in war. Having thus cleared our way to a perfectly definite conception of the *vis viva* of moving masses, we are prepared for the announcement that the heat generated by the shock of a falling body against the earth is proportional to the *vis viva* annihilated. In point of fact, it is not an annihilation at all, but a transference of *vis viva* from the mass to its ultimate particles. This, as we now learn, is proportional to the square of the velocity. In the case, therefore, of two cannon-balls of equal weight, if one strike a target with twice the velocity of the other, it will generate four times the heat; if with three times the velocity, it will generate nine times the heat, and so on.

Mr. Joule has shown that in falling from a height of 772 feet, a body will generate an amount of heat sufficient to raise its own weight of water one degree Fahrenheit in temperature. We have here the *mechanical equivalent* of heat. Now, a body falling from a height of 772 feet, has, upon striking the earth, a velocity of 223 feet a second; and if this velocity were imparted to a body, by any other means, the quantity of heat generated by the stoppage of its motion would be that stated above. Six times that velocity, or 1,338 feet, would not be an inordinate one for a cannon-ball as it quits the gun. Hence, a cannon-ball moving with a velocity of 1,338 feet a second, would, by collision, generate an amount of heat competent to raise its own weight of water 36 degrees Fahrenheit in temperature. If composed of iron, and if all the heat generated were concentrated in the ball itself, its temperature would be raised about 360 degrees Fahrenheit; because one degree in the case of water is equivalent to about ten degrees in the case of iron. In artillery practice, the heat generated is usually concentrated upon the front of the bolt, and on the portion of the target first struck. By this concentration the heat developed becomes sufficiently intense to raise the dust of the metal to incandescence, a flash of light often accompanying collision with the target.

Let us now fix our attention for a moment on the gunpowder which urges the cannon-ball. This is composed of combustible matter, which if burnt in the open air would yield a certain amount of heat. It will not yield this amount if it perform the work of urging a ball. The heat then generated by the gunpowder will fall short of that produced in the open air, by an amount equivalent to the *vis viva* of the ball; and this exact amount is restored by the ball on its collision with the target. In this perfect way are heat and mechanical motion connected.

Broadly enunciated, the principle of the conservation of force asserts, that the quantity of force in the universe is as unalterable as the quantity of matter; that it is alike impossible to create force and to annihilate it. But in what sense are we to understand this assertion? It would be manifestly inapplicable to the force of gravity as defined by Newton; for this is a force varying inversely as the square of the distance; and to affirm the constancy of a varying force would be self-contradictory. Yet, when the question is properly understood, gravity forms no exception to the law of conservation. Following the method pursued by Helmholtz, I will here attempt an elementary exposition of this law. Though destined in its applications to produce momentous changes in human thought, it is not difficult of comprehension.

For the sake of simplicity we will consider a particle of matter, which we may call F, to be perfectly fixed, and a second movable particle, D, placed at a distance from F. We will assume that these two particles attract each other according to the Newtonian law. At a certain distance, the attraction is of a certain definite amount, which might be determined by means of a spring balance. At half this distance the attraction would be augmented four times; at a third of the distance, nine times; at one-fourth of the distance, sixteen times, and so on. In every case, the attraction might be measured by determining, with the spring balance, the amount of tension just sufficient to prevent D from moving towards F. Thus far we have nothing whatever to do with motion; we deal with statics, not with dynamics. We simply take into account the *distance* of D from F, and the *pull* exerted by gravity at that distance.

It is customary in mechanics to represent the magnitude of a force by a line of a certain length, a force of double magnitude being represented by a line of double length, and so on. Placing then the particle D at a distance from F, we can, in imagination, draw a straight line from D to F, and at D erect a perpendicular to this line, which shall represent the amount of the attraction exerted on D. If D be at a very great distance from F, the attraction will be very small, and the perpendicular consequently very short. If the distance be practically infinite, the attraction is practically *nil*. Let us now suppose at every point in the line joining F and D a perpendicular to be erected, proportional in length to the attraction exerted at that point; we thus obtain an infinite number of perpendiculars, of gradually increasing length, as D approaches F. Uniting the ends of all these perpendiculars, we obtain a curve, and between this curve and the straight line joining F and D we have an area containing all the perpendiculars placed side by side. Each one of this infinite series of perpendiculars representing an attraction, or tension, as it is sometimes called, the area just referred to represents the total effort capable of being exerted by the tensions, upon the particle D, during its passage from its first position to F.

Up to the present point we have been dealing with tensions, not with motion. Thus far *vis viva* has been entirely foreign to our contemplation of D and F. Let us now suppose D placed at a practically infinite distance from F; here, as stated, the pull of gravity would be nothing, and the perpendicular representing it would dwindle to a point. In this position the sum of the tensions capable of being exerted on D would be a maximum. Let D now begin to move in obedience to the attraction exerted upon it. Motion being once set up, the idea of *vis viva* arises. In moving towards F the particle D consumes as it were, the tensions. Let us fix our attention on D, at any point of the path over which it is moving. Between that point and F there is a quantity of unused tensions; beyond that point the tensions have been all consumed, but we have in their place an equivalent quantity of *vis viva*. After D has passed any point, the tension previously in store at that point disappears, but not without having added, during the infinitely small duration of its action, a due amount of motion to that previously possessed by D. The nearer D approaches to F, the smaller is the sum of the tensions remaining, but the greater is the living force; the farther D is from F, the greater is the sum of the unconsumed tensions, and the less is the living force. Now the principal of conservation affirms *not* the constancy of the value of the tensions of gravity, nor yet the constancy of the *vis viva*, taken separately, but the absolute constancy of the value of the sum of both. At the beginning the *vis viva* was zero, and the tension area was a maximum; close to F the *vis viva* is a maximum, while the tension area is zero. At every other point, the work-producing power of the particle D consists in part of *vis viva*, and in part of tensions.

If gravity, instead of being attraction, were repulsion, then, with the particles in contact, the sum of the tensions between D and F would be a maximum, and the *vis viva* zero. If, in obedience to the repulsion, D moved away from F, *vis viva* would be generated; and the farther D retreated from F the greater would be its *vis viva*, and the less the amount of tension still available for producing motion. Taking repulsion as well as attraction into account, the principle of the conservation of force affirms that the mechanical value of the *tensions* and *vires vivæ* of the material universe, so far as we know it, is a constant quantity. The universe, in short, possesses two kinds of property which are mutually convertible at an unvarying rate. The diminution of either carries with it the enhancement of the other, the total value of the property remaining unchanged.

The considerations here applied to gravity apply equally to chemical affinity. In a mixture of oxygen and hydrogen the atoms exist apart, but by the application of proper means they may be caused to rush together across the space that separates them. While this space exists, and as long as the atoms have not begun to move towards each other, we have tensions and nothing else. During their motion towards each other the tensions, as in the case of gravity, are converted into *vis viva*. After they clash we have still *vis viva*, but in another form. It *was* translation, it *is* vibration. It *was* molecular transfer, it *is* heat.

It is possible to reverse these processes, to unlock the embrace of the atoms and replace them in their first positions. But, to accomplish this, as much heat would be required as was generated by their union. Such reversals occur daily and hourly in nature. By the solar waves, the oxygen of water is divorced from its hydrogen in the leaves of plants. As molecular *vis viva* the waves disappear, but in so doing they re-endow the atoms of oxygen and hydrogen with *tension*. The atoms are thus enabled to recombine, and when they do so they restore the precise amount of heat consumed in their separation. The same remarks apply to the compound of carbon and oxygen, called carbonic acid, which is exhaled from our lungs, produced by our fires, and found sparingly diffused everywhere throughout the air. In the leaves of plants the sunbeams also wrench the atoms of carbonic acid asunder, and sacrifice themselves in the act; but when the plants are burnt, the amount of heat consumed in their production is restored.

This, then, is the rhythmic play of Nature as regards her forces. Throughout all her regions she oscillates from tension to *vis viva*, from *vis viva* to tension. We have the same play in the planetary system. The earth's orbit is an ellipse, one of the foci of which is occupied by the sun. Imagine the earth at the most distant part of the orbit. Her motion, and consequently her *vis viva*, is then a minimum. The planet rounds the curve, and begins its approach to the sun. In front it has a store of tensions, which is gradually consumed, an equivalent amount of *vis viva* being generated. When nearest to the sun the motion, and consequently the *vis viva*, reach a maximum. But here the available tensions have been used up. The earth rounds this portion of the curve and retreats from the sun. Tensions are now stored up, but *vis viva* is lost, to be again restored at the expense of the complementary force on the opposite side of the curve. Thus beats the heart of the universe, but without increase or diminution of its total stock of force.

I have thus far tried to steer clear amid confusion, by fixing the mind of the reader upon things rather than upon names. But good names are essential; and here, as yet, we are not provided with such. We have had the force of gravity and living force—two utterly distinct things. We have had pulls and tensions; and we might have had the force of heat, the force of light, the force of magnetism, or the force of electricity—all of which terms have been employed more or less loosely by writers on physics. This confusion is happily avoided by the introduction of the term 'energy,' which embraces both *tension* and *vis viva.* Energy is possessed by bodies already in motion; it is then actual, and we agree to call it *actual* or *dynamic energy.* It is our old *vis viva.* On the other hand, energy is possible to bodies not in motion, but which, in virtue of attraction or repulsion, possess a power of motion which would realise itself if all hindrances were removed. Looking, for example, at gravity; a body on the earth's surface in a position from which it cannot fall to a lower one possesses no energy. It has neither motion nor power of motion. But the same body suspended at a height above the earth has a power of motion, though it may not have exercised it. Energy is possible to such a body, and we agree to call this *potential energy.* It consists of our old tensions. We, moreover, speak of the conservation of energy, instead of the conservation of force; and say that the sum of the potential and dynamic energies of the material universe is a constant quantity.

A body cast upwards consumes the actual energy of projection, and lays up potential energy. When it reaches its utmost height all its actual energy is consumed, its potential energy being then a maximum. When it returns, there is a reconversion of the potential into the actual. A pendulum at the limit of its swing possesses potential energy; at the lowest point of its arc its energy is all actual. A patch of snow *resting* on a mountain slope has potential energy; loosened, and shooting down as an avalanche, it possesses dynamic energy. The pine-trees growing on the Alps have potential energy; but rushing down the *Holzrinne* of the woodcutters they possess actual energy. The same is true of the mountains themselves. As long as the rocks which compose them can fall to a lower level, they possess potential energy, which is converted into actual when the frost ruptures their cohesion and hands them over to the action of gravity. The hammer of the great bell of Westminster, when raised before striking, possesses potential energy; when it falls, the energy becomes dynamic; and after the stroke, we have the rhythmic play of potential and dynamic in the vibrations of the bell. The same holds good for the molecular oscillations of a heated body. An atom is driven against its neighbour, and recoils. The ultimate amplitude of the recoil being attained, the motion of the atom in that direction is checked, and for an instant its energy is all potential. It is then drawn towards its neighbour with accelerated speed; thus, by attraction, converting its potential into dynamic energy. Its motion in this direction is also finally checked, and again, for an instant, its energy is all potential. It once more retreats, converting, by repulsion, its potential into dynamic energy, till the latter attains a maximum, after which it is again changed into potential energy. Thus, what is true of the earth, as she swings to and fro in her yearly journey round the sun, is also true of her minutest atom. We have wheels within wheels, and rhythm within rhythm.

When a body is heated, a change of molecular arrangement always occurs, and to produce this change heat is consumed. Hence, a portion only of the heat communicated to the body remains as dynamic energy. Looking back on some of the statements made at the beginning of this article, now that our knowledge is more extensive, we see the necessity of qualifying them. When, for example, two bodies clash, heat is generated; but the heat, or molecular dynamic energy, developed at the moment of collision, is not the equivalent of the sensible dynamic energy destroyed. The true equivalent is this heat, plus the potential energy conferred upon the molecules by the placing of greater distances between them. This molecular potential energy is afterwards, on the cooling of the body, converted into heat.

Wherever two atoms capable of uniting together by their mutual attractions exist separately, they form a store of potential energy. Thus our woods, forests, and coal-fields on the one hand, and our atmospheric oxygen on the other, constitute a vast store of energy of this kind —vast, but far from infinite. We have, besides our coal-fields, metallic bodies more or less sparsely distributed through the earth's crust. These bodies can be oxydised; and hence they are, so far as they go, stores of potential energy. But the attractions of the great mass of the earth's crust are already satisfied, and from them no further energy can possibly be obtained. Ages ago the elementary constituents of our rocks clashed together and produced the motion of heat, which was taken up by the aether and carried away through stellar space. It is lost for ever as far as we are concerned. In those ages the hot conflict of carbon, oxygen, and calcium produced the chalk and limestone hills which are now cold; and from this carbon, oxygen, and calcium no further energy can be derived. So it is with almost all the other constituents of the earth's crust. They took their present form in obedience to molecular force; they turned their potential energy into dynamic, and gave it to the universe, ages before man appeared upon this planet. For him a residue of potential energy remains, vast, truly, in relation to the life and wants of an individual, but exceedingly minute in comparison with the earth's primitive store.

To sum up. The whole stock of energy or working-power in the world consists of *attractions*, *repulsions*, and *motions*. If the attractions and repulsions be so circumstanced as to be able to produce motion, they are sources of working-power, but not otherwise. As stated a moment ago, the attraction exerted between the earth and a body at a distance from the earth's surface, is a source of working-power; because the body can be moved by the attraction, and in falling to the earth can perform work. When it rests upon the earth's surface it is not a source of power or energy, because it can fall no farther. But though it has ceased to be a source of *energy*, the attraction of gravity still acts as a *force*, which holds the earth and weight together.

The same remarks apply to attracting atoms and molecules. As long as distance separates them, they can move across it in obedience to the attraction; and the motion thus produced may, by proper appliances, be caused to perform mechanical work. When, for example, two atoms of hydrogen unite with one of oxygen, to form water, the atoms are first drawn towards each other—they move, they clash, and then by virtue of their resiliency, they recoil and quiver. To this quivering motion we give the name of heat. This atomic vibration is merely the redistribution of the motion produced by the chemical affinity; and this is the only sense in which chemical affinity can be said to be converted into heat. We must not imagine the chemical *attraction* destroyed, or converted into anything else. For the atoms, when mutually clasped to form a molecule of water, are held together by the very attraction which first drew them towards each other. That which has really been expended is the *pull* exerted through the space by which the distance between the atoms has been diminished.

If this be understood, it will be at once seen that gravity may, in this sense, be said to be convertible into heat; that it is in reality no more an outstanding and inconvertible agent, as it is sometimes stated to be, than is chemical affinity. By the exertion of a certain pull through a certain space, a body is caused to clash with a certain definite velocity against the earth. Heat is thereby developed, and this is the only sense in which gravity can be said to be converted into heat. In no case is the *force* which produces the motion annihilated or changed into anything else. The mutual attraction of the earth and weight exists when they are in contact, as when they were separate; but the ability of that attraction to employ itself in the production of motion does not exist.

The transformation, in this case, is easily followed by the mind's eye. First, the weight as a whole is set in motion by the attraction of gravity. This motion of the mass is arrested by collision with the earth, being broken up into molecular tremors, to which we give the name of heat.

And when we reverse the process, and employ those tremors of heat to raise a weight, which is done through the intermediation of an elastic fluid in the steam-engine, a certain definite portion of the molecular motion is consumed. In this sense, and in this sense only, can the heat be said to be converted into gravity; or, more correctly, into potential energy of gravity. Here the destruction of the heat has created no *new* attraction; but the old attraction has conferred upon it a power of exerting a certain definite pull, between the starting-point of the falling weight and the earth.

When, therefore, writers on the conservation of energy speak of tensions being 'consumed' and 'generated,' they do not mean thereby that old attractions have been annihilated, and new ones brought into existence, but that, in the one case, the power of the attraction to produce motion has been diminished by the shortening of the distance between the attracting bodies, while, in the other case, the power of producing motion has been augmented by the increase of the distance. These remarks apply t all bodies, whether they be sensible masses or molecules.

Of the inner quality that enables matter to attrac matter we know nothing; and the law of conservatio makes no statement regarding that quality. It takes the facts of attraction as they stand, and affirms only the constancy of working-power. That power may exist in the form of MOTION; or it may exist in the form of FORCE, *with distance to act through.* The former is dynamic energy, the latter is potential energy, the constancy of the sum of both being affirmed by the law of conservation. The convertibility of natural forces consists solely in transformations of dynamic into potential, and of potential into dynamic energy. In no other sense has the convertibility of force any scientific meaning.

From the writings and conversation of distinguished men I learned, that the notion of gravity being an outstanding force, entirely inconvertible, was prevalent among them. Hence the origin of the foregoing exposition. Grave errors have, indeed, been entertained, as to what is really intended to be conserved by the doctrine of conservation. November 1875.

II.

RADIATION.

1865.

1. *Visible and Invisible Radiation.*

BETWEEN the mind of man and the outer world are interposed the nerves of the human body, which translate, or enable the mind to translate, the impressions of that world into facts of consciousness and thought.

Different nerves are suited to the perception of different impressions. We do not see with the ear, nor hear with the eye, nor are we rendered sensible of sound by the nerves of the tongue. Out of the general assemblage of physical actions, each nerve, or group of nerves, selects and responds to those for the perception of which it is specially organised.

The optic nerve passes from the brain to the back of the eyeball and there spreads out, to form the retina, a web of nerve filaments, on which the images of external objects are projected by the optical portion of the eye. This nerve is limited to the apprehension of the phenomena of radiation, and, notwithstanding its marvellous sensibility to certain impressions of this class, it is singularly obtuse to other impressions.

Nor does the optic nerve embrace the entire range even of radiation. Some rays, when they reach it, are incompetent to evoke its power, while others never reach it at all, being absorbed by the humours of the eye. To all rays which, whether they reach the retina or not, fail to excite vision, we give the name of invisible or obscure rays. All non-luminous bodies emit such rays. There is no body in nature absolutely cold, and every body not absolutely cold emits rays of heat. But to render radiant heat fit to affect the optic nerve a certain temperature is necessary. A cool poker thrust into a fire remains dark for a time, but when its temperature has become equal to that of the surrounding coals, it glows like them. In like manner, if a current of electricity, of gradually increasing strength, be sent through a wire of the refractory metal platinum, the wire first becomes sensibly warm to the touch; for a time its heat augments, still however remaining obscure; at length we can no longer touch the metal with impunity; and at a certain definite temperature it emits a feeble red light. As the current augments in power the light augments in brilliancy, until finally the wire appears of a dazzling white. The light which it now emits is similar to that of the sun.

By means of a prism Sir Isaac Newton unravelled the texture of solar light, and by the same simple instrument we can investigate the luminous changes of our platinum wire. In passing through the prism all its rays (and they are infinite in variety) are bent or refracted from their straight course; and, as different rays are differently refracted by the prism, we are by it enabled to separate one class of rays from another. By such prismatic analysis Dr. Draper has shown, that when the platinum wire first begins to glow, the light emitted is sensibly red. As the glow augments the red becomes more brilliant, but at the same time orange rays are added to the emission. Augmenting the temperature still further, yellow rays appear beside the orange; after the yellow, green rays are emitted; and after the green come, in succession, blue, indigo, and violet rays. To display all these colours at the same time the platinum wire must be *white-hot:* the impression of whiteness being in fact produced by the simultaneous action of all these colours on the optic nerve.

In the experiment just described we began with a platinum wire at an ordinary temperature, and gradually raised it to a white heat. At the beginning, and even before the electric current had acted at all upon the wire, it emitted invisible rays. For some time after the action of the current had commenced, and even for a time after the wire had become intolerable to the touch, its radiation was still invisible. The question now arises, What becomes of these invisible rays when the visible ones make their appearance? It will be proved in the sequel that they maintain themselves in the radiation; that a ray once emitted continues to be emitted when the temperature is increased, and hence the emission from our platinum wire, even when it has attained its maximum brilliancy, consists of a mixture of visible and invisible rays. If, instead of the platinum wire, the earth itself were raised to incandescence, the obscure radiation which it now emits would continue to be emitted. To reach incandescence the planet would have to pass through all the stages of non-luminous radiation, and the final emission would embrace the rays of all these stages. There can hardly be a doubt that from the sun itself, rays proceed similar in kind to those which the dark earth pours nightly into space. In fact, the various kinds of obscure rays emitted by all the planets of our system are included in the present radiation of the sun.

The great pioneer in this domain of science was Sir William Herschel. Causing a beam of solar light to pass through a prism, he resolved it into its coloured constituents; he formed what is technically called the solar spectrum. Exposing thermometers to the successive colours he determined their heating power, and found it to augment from the violet or most refracted end, to the red or least refracted end of the spectrum. But he did not stop here. Pushing his thermometers into the dark space beyond the red he found that, though the light had disappeared, the radiant heat falling on the instruments was more intense than that at any visible part of the spectrum. In fact, Sir William Herschel showed, and his results have been verified by various philosophers since his time, that, besides its luminous rays, the sun pours forth a multitude of other rays, more powerfully calorific than the luminous ones, but entirely unsuited to the purposes of vision.

At the less refrangible end of the solar spectrum, then, the range of the sun's radiation is not limited by that of the eye. The same statement applies to the more refrangible end. Ritter discovered the extension of the spectrum into the invisible region beyond the violet; and, in recent times, this ultra-violet emission has had peculiar interest conferred upon it by the admirable researches of Professor Stokes. The complete spectrum of the sun consists, therefore, of three distinct parts:—first, of ultra-red rays of high heating power, but unsuited to the purposes of vision; secondly, of luminous rays which display the succession of colours, red, orange, yellow, green, blue, indigo, violet; thirdly, of ultra-violet rays which, like the ultra-red ones, are incompetent to excite vision, but which, unlike the ultra-red rays, possess a very feeble heating power. In consequence, however, of their chemical energy these ultra-violet rays are of the utmost importance to the organic world.

igin and Character of Radiation. The Aether.

en we see a platinum wire raised gradually to a
eat, and emitting in succession all the colours of the
n, we are simply conscious of a series of changes
condition of our own eyes. We do not see the
in which these successive colours originate, but the
resistibly infers that the appearance of the colours
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What is the nature of these changes? In virtue
condition does the wire radiate at all? We must
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vibration. In this vibration, indeed, consists such
as the wire then possesses. Locke enunciated this
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in our sensations is *heat* in the object is nothing
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wider ranges. Technically speaking, the *ampli-*
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our first exhibited is red, which corresponds to the
rate of vibration of which the eye is able to take

cognisance. By augmenting the strength of the electric current more rapid vibrations are introduced, and orange rays appear. A quicker rate of vibration produces yellow, a still quicker green; and by further augmenting the rapidity, we pass through blue, indigo, and violet, to the extreme ultra-violet rays.

Such are the changes which science recognises in the wire itself, as concurrent with the visual changes taking place in the eye. But what connects the wire with this organ? By what means does it send such intelligence of its varying condition to the optic nerve? Heat being, as defined by Locke, 'a very brisk agitation of the insensible parts of an object,' it is readily conceivable that on *touching* a heated body the agitation may communicate itself to the adjacent nerves, and announce itself to them as light or heat. But the optic nerve does not touch the hot platinum, and hence the pertinence of the question, By what agency are the vibrations of the wire transmitted to the eye?

The answer to this question involves perhaps the most important physical conception that the mind of man has yet achieved: the conception of a medium filling space and fitted mechanically for the transmission of the vibrations of light and heat, as air is fitted for the transmission of sound. This medium is called the *luminiferous aether*. Every vibration of every atom of our platinum wire raises in this aether a wave, which speeds through it at the rate of 186,000 miles a second. The aether suffers no rupture of continuity at the surface of the eye, the inter-molecular spaces of the various humours are filled with it; hence the waves generated by the glowing platinum can cross these humours and impinge on the optic nerve at the back of the eye. Thus the sensation of light reduces itself to the communication of motion. Up to this point we deal with pure mechanics; but the subsequent translation of the shock of the aethereal waves into consciousness eludes the analysis of science. As an oar dipping into the Cam generates systems of waves, which, speeding from the centre of disturbance, finally stir the sedges on the river's bank, so do the vibrating atoms generate in the surrounding aether undulations, which finally stir the filaments of the retina. The motion thus imparted is transmitted with measurable, and not very great velocity to the brain, where, by a process which science does not even tend to unravel, the tremor of the nervous matter is converted into the conscious impression of light.

Darkness might then be defined as aether at rest; light as aether in motion. But in reality the aether is never at rest, for in the absence of light-waves we have heat-waves always speeding through it. In the spaces of the universe both classes of undulations incessantly commingle. Here the waves issuing from uncounted centres cross, coincide, oppose, and pass through each other, without confusion or ultimate extinction. The waves from the zenith do not jostle out of existence those from the horizon, and every star is seen across the entanglement of wave-motions produced by all other stars. It is the ceaseless thrill caused by those distant orbs collectively in the aether, that constitutes what we call *the temperature of space.* As the air of a room accommodates itself to the requirements of an orchestra, transmitting each vibration of every pipe and string, so does the inter-stellar aether accommodate itself to the requirements of light and heat. Its waves mingle in space without disorder, each being endowed with an individuality as indestructible as if it alone had disturbed the universal repose.

All vagueness with regard to the use of the terms *radiation* and *absorption* will now disappear. Radiation is the communication of vibratory motion to the aether; and when a body is said to be chilled by radiation, as for example the grass of a meadow on a starlight night, the meaning is, that the molecules of the grass have lost a portion of their motion, by imparting it to the medium in which they vibrate. On the other hand, the waves of aether may so strike against the molecules of a body exposed to their action as to yield up their motion to the latter; and in this transfer of the motion from the aether to the molecules consists the absorption of radiant heat. All the phenomena of heat are in this way reducible to interchanges of motion; and it is purely as the recipients or the donors of this motion, that we ourselves become conscious of the action of heat and cold.

3. *The Atomic Theory in reference to the Aether.*

The word 'atoms' has been more than once employed in this discourse. Chemists have taught us that all matter is reducible to certain elementary forms to which they give this name. These atoms are endowed with powers of mutual attraction, and under suitable circumstances they coalesce to form compounds. Thus oxygen and hydrogen are elements when separate, or merely *mixed*, but they may be made to *combine* so as to form molecules, each consisting of two atoms of hydrogen and one of oxygen. In this condition they constitute water. So also chlorine and sodium are elements, the former a pungent gas, the latter a soft metal; and they unite together to form chloride of sodium or common salt. In the same way the element nitrogen combines with hydrogen, in the proportion of one atom of the former to three of the latter, to form ammonia, or spirit of hartshorn. Picturing in imagination the atoms of elementary bodies as little spheres, the molecules of compound bodies must be pictured as groups of such spheres. This is the atomic theory as

Dalton conceived it. Now if this theory have any foundation in fact, and if the theory of an aether pervading space, and constituting the vehicle of atomic motion, be founded in fact, we may assuredly expect the vibrations of elementary bodies to be profoundly modified by the act of combination. It is on the face of it almost certain that both as regards radiation and absorption, that is to say, both as regards the communication of motion to the aether, and the acceptance of motion from it, the deportment of the uncombined atoms will be different from that of the combined.

4. *Absorption of Radiant Heat by Gases.*

We have now to submit these considerations to the only test by which they can be tried, namely, that of experiment. An experiment is well defined as a question put to Nature; but, to avoid the risk of asking amiss, we ought to purify the question from all adjuncts which do not necessarily belong to it. Matter has been shown to be composed of elementary constituents, by the compounding of which all its varieties are produced. But, besides the chemical unions which they form, both elementary and compound bodies can unite in another and less intimate way. By the attraction of cohesion gases and vapours aggregate to liquids and solids, without any change of their chemical nature. We do not yet know how the transmission of radiant heat may be affected by the entanglement due to cohesion; and, as our object now is to examine the influence of chemical union alone, we shall render our experiments more pure by liberating the atoms and molecules entirely from the bonds of cohesion, and employing them in the gaseous or vaporous form.

Let us endeavour to obtain a perfectly clear mental image of the problem now before us. Limiting in the first place our enquiries to the phenomena of absorption, we have to picture a succession of waves issuing from a radiant source and passing through a gas; some of them striking against the gaseous molecules and yielding up their motion to the latter; others gliding round the molecules, or passing through the inter-molecular spaces without apparent hindrance. The problem before us is to determine whether such free molecules have any power whatever to stop the waves of heat; and if so, whether different molecules possess this power in different degrees.

The source of waves chosen for these experiments is a plate of copper, against the back of which a steady sheet of flame is permitted to play. On emerging from the copper, the waves, in the first instance, pass through a space devoid of air, and then enter a hollow glass cylinder, three feet long and three inches wide. The two ends of this cylinder are stopped by two plates of rock-salt, this being the only solid substance which offers a scarcely sensible obstacle to the passage of the calorific waves. After passing through the tube, the radiant heat falls upon the anterior face of a thermo-electric pile,[1] which instantly applies the heat to the generation of an electric current. This current conducted round a magnetic needle deflects it, and the magnitude of the deflection is a measure of the heat falling upon the pile. This famous instrument, and not an ordinary thermometer, is what we shall use in these enquiries, but we shall use it in a somewhat novel way. As long as the two opposite faces of the thermo-electric pile are kept at the same temperature, no matter how high that may be, there is no current generated. The current is a consequence of a

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[1] In the Appendix to the first chapter of 'Heat as a Mode of Motion' the construction of the thermo-electric pile is fully explained.

difference of temperature between the two opposite faces of the pile. Hence, if after the anterior face has received the heat from our radiating source, a second source, which we may call the compensating source, be permitted to radiate against the posterior face, this latter radiation will tend to neutralise the former. When the neutralisation is perfect, the magnetic needle connected with the pile is no longer deflected, but points to the zero of the graduated circle over which it hangs.

And now let us suppose the glass tube, through which pass the waves from the heated plate of copper, to be exhausted by an air-pump, the two sources of heat acting at the same time on the two opposite faces of the pile. Perfectly equal quantities of heat being imparted to the two faces, the needle points to zero. Let any gas be now permitted to enter the exhausted tube; if the molecules possess any power of intercepting the calorific waves, the equilibrium previously existing will be destroyed, the compensating source will triumph, and a deflection of the magnetic needle will be the immediate consequence. From the deflections thus produced by different gases, we can readily deduce the relative amounts of wave-motion which their molecules intercept.

In this way the substances mentioned in the following table were examined, a small portion only of each being admitted into the glass tube. The quantity admitted was just sufficient to depress a column of mercury associated with the tube one inch: in other words, the gases were examined at a pressure of one-thirtieth of an atmosphere. The numbers in the table express the relative amounts of wave-motion absorbed by the respective gases, the quantity intercepted by atmospheric air being taken as unity.

Radiation through Gases.

Name of gas	Relative absorption
Air	1
Oxygen	1
Nitrogen	1
Hydrogen	1
Carbonic oxide	750
Carbonic acid	972
Hydrochloric acid	1,005
Nitric oxide	1,590
Nitrous oxide	1,860
Sulphide of hydrogen	2,100
Ammonia	5,460
Olefiant gas	6,030
Sulphurous acid	6,480

Every gas in this table is perfectly transparent to light, that is to say, all waves within the limits of the visible spectrum pass through it without obstruction; but for the waves of slower period, emanating from our heated plate of copper, enormous differences of absorptive power are manifested. These differences illustrate in the most unexpected manner the influence of chemical combination. Thus the elementary gases, oxygen, hydrogen, and nitrogen, and the mixture atmospheric air, prove to be practical vacua to the rays of heat; for every ray, or, more strictly speaking, for every unit of wave-motion, which any one of them is competent to intercept, perfectly transparent ammonia intercepts 5,460 units, olefiant gas 6,030 units, while sulphurous acid gas absorbs 6,480 units. What becomes of the wave-motion thus intercepted? It is applied to the heating of the absorbing gas. Through air, oxygen, hydrogen, and nitrogen, on the contrary, the waves of äether pass without absorption, and these gases are not sensibly changed in temperature by the most powerful calorific rays. The position of nitrous oxide in the foregoing table is worthy of particular notice. In this gas we have the same atoms in a state of chemical union, that exist uncombined in the atmosphere; but the absorption of the compound is 1,800 times that of air.

5. *Formation of Invisible Foci.*

This extraordinary deportment of the elementary gases naturally directed attention to elementary bodies in other states of aggregation. Some of Melloni's results now attained a new significance; for this celebrated experimenter had found crystals of the element sulphur to be highly pervious to radiant heat; he had also proved that lamp-black, and black glass, (which owes its blackness to the element carbon) were to a considerable extent transparent to calorific rays of low refrangibility. These facts, harmonising so strikingly with the deportment of the simple gases, suggested further enquiry. Sulphur dissolved in bisulphide of carbon was found almost perfectly transparent. The dense and deeply-coloured element bromine was examined, and found competent to cut off the light of our most brilliant flames, while it transmitted the invisible calorific rays with extreme freedom. Iodine, the companion element of bromine, was next thought of, but it was found impracticable to examine the substance in its usual solid condition. It however dissolves freely in bisulphide of carbon. There is no chemical union between the liquid and the iodine; it is simply a case of solution, in which the uncombined atoms of the element can act upon the radiant heat. When permitted to do so, it was found that a layer of dissolved iodine, sufficiently opaque to cut off the light of the midday sun, was almost absolutely transparent to the invisible calorific rays.

By prismatic analysis Sir William Herschel separated the luminous from the non-luminous rays of the sun, and he also sought to render the obscure rays visible by concentration. Intercepting the luminous portion of his spectrum he brought, by a converging lens, the ultra-red rays to a focus, but by this condensation he obtained no light. The solution of iodine offers a means of filtering the solar beam, or, failing it, the beam of the electric lamp, which renders attainable far more powerful foci of invisible rays than could possibly be obtained by the method of Sir William Herschel. For to form his spectrum he was obliged to operate upon solar light which had passed through a narrow slit or through a small aperture, the amount of the obscure heat being limited by this circumstance. But with our opaque solution we may employ the entire surface of the largest lens, and having thus converged the rays, luminous and non-luminous, we can intercept the former by the iodine, and do what we please with the latter. Experiments of this character, not only with the iodine solution, but also with black glass and layers of lamp-black, were publicly performed at the Royal Institution in the early part of 1862, and the effects at the foci of invisible rays, then obtained, were such as had never been witnessed previously.

In the experiments here referred to, glass lenses were employed to concentrate the rays. But glass, though highly transparent to the luminous, is in a high degree opaque to the invisible, heat-rays of the electric lamp, and hence a large portion of those rays was intercepted by the glass. The obvious remedy here is to employ rock-salt lenses instead of glass ones, or to abandon the use of lenses wholly, and to concentrate the rays by a metallic mirror. Both of these improvements have been introduced, and, as anticipated, the invisible foci have been thereby rendered more intense. The mode of operating remains however the same, in principle, as that made known in 1862. It was then found that an instant's exposure of the face of the thermo-electric pile to the focus of invisible rays, dashed the needles of a coarse galvanometer violently aside. It is now found that, on substituting for the face of the thermo-electric pile a combustible body, the invisible rays are competent to set that body on fire.

6. *Visible and Invisible Rays of the Electric Light.*

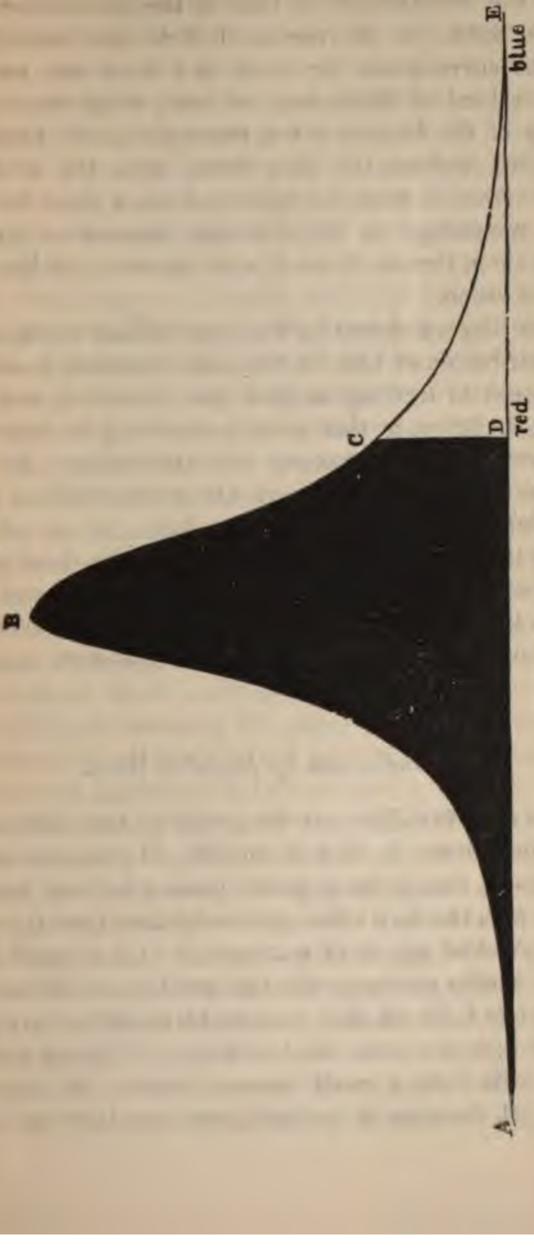
We have next to examine what proportion the non-luminous rays of the electric light bear to the luminous ones. This the opaque solution of iodine enables us to do with an extremely close approximation to the truth. The pure bisulphide of carbon, which is the solvent of the iodine, is perfectly transparent to the luminous, and almost perfectly transparent to the dark, rays of the electric lamp. Through the transparent bisulphide the total radiation of the lamp may be considered to pass, while through the solution of iodine only the dark rays are transmitted. Determining, then, by means of a thermo-electric pile, the total radiation, and deducting from it the purely obscure, we obtain the amount of the purely luminous emission. Experiments, performed in this way, prove that if all the visible rays of the electric light were converged to a focus of dazzling brilliancy, its heat would only be one-eighth of that produced at the unseen focus of the invisible rays.

Exposing his thermometers to the successive colours of the solar spectrum, Sir William Herschel determined the heating power of each, and also that of the region beyond the extreme red. Then drawing a straight line to represent the length of the spectrum, he erected, at various points, perpendiculars to represent the calorific intensity existing at those points. Uniting the ends of all his perpendiculars, he obtained a curve which showed at a glance the manner in which the heat was distributed in the solar spectrum. Professor Müller of Freiburg, with improved instruments, afterwards made similar experiments, and constructed a more accurate diagram of the same kind. We have now to examine the distribution of heat in the spectrum of the electric light; and for this purpose we shall employ a particular form of the thermo-electric pile, devised by Melloni. Its face is a rectangle, which by means of movable side-pieces can be rendered as narrow as desired. We can, for example, have the face of the pile the tenth, the hundredth, or even the thousandth of an inch in breadth. By means of an endless screw, this *linear* thermo-electric pile may be moved through the entire spectrum, from the violet to the red, the amount of heat falling upon the pile at every point of its march, being declared by a magnetic needle associated with the pile.

When this instrument is brought up to the violet end of the spectrum of the electric light, the heat is found to be insensible. As the pile gradually moves from the violet end towards the red, heat soon manifests itself, augmenting as we approach the red. Of all the colours of the visible spectrum the red possesses the highest heating power. On pushing the pile into the dark region beyond the red, the heat, instead of vanishing, rises suddenly and enormously in intensity, until at some distance beyond the red it attains a maximum. Moving the pile still forward, the thermal power falls, somewhat more rapidly than it rose. It then gradually shades away, but, for a distance beyond the red greater than the length of the whole visible spectrum, signs of heat may be detected.

Drawing a datum line, and erecting along it perpendiculars, proportional in length to the thermal intensity at the respective points, we obtain the extraordinary curve, shown on the adjacent page, which ex-

Fig. 1.



Spectrum of Electric Light.

hibits the distribution of heat in the spectrum of the electric light. In the region of dark rays, beyond the red, the curve shoots up to B, in a steep and massive peak—a kind of Matterhorn of heat, which dwarfs the portion of the diagram C D E, representing the luminous radiation. Indeed, the idea forced upon the mind by this diagram is that the light rays are a mere insignificant appendage to the heat-rays represented by the area A B C D, thrown in as it were by nature for the purposes of vision.

The diagram drawn by Professor Müller to represent the distribution of heat in the solar spectrum is not by any means so striking as that just described, and the reason, doubtless, is that prior to reaching the earth the solar rays have to traverse our atmosphere. By the aqueous vapour there diffused, the summit of the peak representing the sun's invisible radiation is cut off. A similar lowering of the mountain of invisible heat is observed when the rays from the electric light are permitted to pass through a film of water, which acts upon them as the atmospheric vapour acts upon the rays of the sun.

7. *Combustion by Invisible Rays.*

The sun's invisible rays far transcend the visible ones in heating power, so that if the alleged performances of Archimedes during the siege of Syracuse had any foundation in fact, the dark solar rays would have been the philosopher's chief agents of combustion. On a small scale we can readily produce, with the purely invisible rays of the electric light, all that Archimedes is said to have performed with the sun's total radiation. Placing behind the electric light a small concave mirror, the rays are converged, the cone of reflected rays and their point of convergence being rendered clearly visible by the dust always floating in the air. Placing between the luminous focus and the source of rays our solution of iodine, the light of the cone is entirely cut away; but the intolerable heat experienced when the hand is placed, even for a moment, at the dark focus, shows that the calorific rays pass unimpeded through the opaque solution.

Almost anything that ordinary fire can effect may be accomplished at the focus of invisible rays; the *air* at the focus remaining at the same time perfectly cold, on account of its transparency to the heat-rays. An air thermometer, with a hollow rock-salt bulb, would be unaffected by the heat of the focus: there would be no expansion, and in the open air there is no convection. The aether at the focus, and not the air, is the substance in which the heat is embodied. A block of wood, placed at the focus, absorbs the heat, and dense volumes of smoke rise swiftly upwards, showing the manner in which the air itself would rise, if the invisible rays were competent to heat it. At the perfectly dark focus dry paper is instantly inflamed: chips of wood are speedily burnt up: lead, tin, and zinc are fused: and disks of charred paper are raised to vivid incandescence. It might be supposed that the obscure rays would show no preference for black over white; but they do show a preference, and to obtain rapid combustion, the body, if not already black, ought to be blackened. When metals are to be burned, it is necessary to blacken or otherwise tarnish them, so as to diminish their reflective power. Blackened zinc foil, when brought into the focus of invisible rays, is instantly caused to blaze, and burns with its peculiar purple flame. Magnesium wire flattened, or tarnished magnesium ribbon, also bursts into splendid combustion. Pieces of charcoal suspended in a receiver full of oxygen are also set on fire: the dark rays, after having passed through the receiver, still possessing sufficient power to ignite the charcoal, and thus initiate the attack of the oxygen. If, instead of being plunged in oxygen, the charcoal be suspended in vacuo, it immediately glows at the place where the focus falls.

8. *Transmutation of Rays:*[1] *Calorescence.*

Eminent experimenters were long occupied in demonstrating the substantial identity of light and radiant heat, and we have now the means of offering a new and striking proof of this identity. A concave mirror produces, beyond the object which it reflects, an inverted and magnified image of the object; withdrawing, for example, our iodine solution, an intensely luminous inverted image of the carbon points of the electric light is formed at the focus of the mirror employed in the foregoing experiments. When the solution is interposed, and the light is cut away, what becomes of this image? It disappears from sight; but an invisible thermograph remains, and it is only the peculiar constitution of our eyes that disqualifies us from seeing the picture formed by the calorific rays. Falling on white paper, the image chars itself out: falling on black paper, two holes are pierced in it, corresponding to the images of the two coke points: but falling on a thin plate of carbon in vacuo, or upon a thin sheet of platinised platinum, either in vacuo or in air, radiant heat is converted into light, and the image stamps itself in vivid incandescence upon both the carbon and the metal. Results similar to those obtained with the electric light have also been obtained with the invisible rays of the lime-light and of the sun.

Before a Cambridge audience it is hardly necessary to refer to the excellent researches of Professor Stokes at the opposite end of the spectrum. The above results constitute a kind of complement to his discoveries. Professor Stokes named the phenomena which he has discovered and investigated *Fluorescence*; for the new phenomena here described I have proposed the term *Calorescence*. He, by the interposition of a proper medium, so lowered the refrangibility of the ultra-violet rays of the spectrum as to render them visible. Here, by the interposition of the platinum foil, the refrangibility of the ultra-red rays is so exalted as to render them visible. Looking through a prism at the incandescent image of the carbon points, the light of the image is decomposed, and a complete spectrum obtained. The invisible rays of the electric light, remoulded by the atoms of the platinum, shine thus visibly forth; ultra-red rays being converted into red, orange, yellow, green, blue, indigo, violet, and ultra-violet ones. Could we, moreover, raise the original source of rays to a sufficiently high temperature, we might not only obtain from the dark rays of such a source a single incandescent image, but from the dark rays of this image we might obtain a second one, from the dark rays of the second a third, and so on—a series of complete images and spectra being thus extracted from the invisible emission of the primitive source.[1]

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[1] I borrow this term from Professor Challis, 'Philosophical Magazine, . xii. p. 521.

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[1] On investigating the calorescence produced by rays transmitted through glasses of various colours, it was found that in the case of certain specimens of blue glass, the platinum foil glowed with a *pink* or *purplish* light. The effect was not subjective, and considerations of obvious interest are suggested by it. Different kinds of black glass differ notably as to their power of transmitting radiant heat. In thin plates some descriptions tint the sun with a greenish hue: others make it appear a glowing red without any trace of green. The latter are far more diathermic than the former. In fact, carbon when perfectly dissolved, and incorporated with a good white glass, is highly transparent to the calorific rays, and by employing it as an absorbent the phenomena of 'calorescence' may be obtained, though in a less striking form than with the iodine. The black glass chosen for thermometers, and intended to absorb completely the solar heat, may entirely fail in this object, if the glass in which the carbon is incorporated be

9. *Deadness of the Optic Nerve to the Calorific Rays.*

The layer of iodine used in the foregoing experiments intercepted the rays of the noonday sun. No trace of light from the electric lamp was visible in the darkest room, even when a white screen was placed at the focus of the mirror employed to concentrate the light. It was thought, however, that if the retina itself were brought into the focus the sensation of light might be experienced. The danger of this experiment was twofold. If the dark rays were absorbed in a high degree by the humours of the eye the albumen of the humours might coagulate along the line of the rays. If, on the contrary, no such high absorption took place, the rays might reach the retina with a force sufficient to destroy it. To test the likelihood of these results, experiments were made on water and on a solution of alum, and they showed it to be very improbable that in the brief time requisite for an experiment any serious damage could be done. The eye was therefore caused to approach the dark focus, no defence, in the first instance, being provided; but the heat, acting upon the parts surrounding the pupil, could not be borne. An aperture was therefore pierced in a plate of metal, and the eye, placed behind the aperture, was caused to approach the point of convergence of invisible rays. The focus was attained, first by the pupil and afterwards by the retina. Removing the eye, but permitting the plate of metal to remain, a sheet of platinum foil was placed in the position occupied by the retina a moment before. The platinum

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colourless. To render the bulb of a thermometer a perfect absorbent, the glass ought in the first instance to be green. Soon after the discovery of fluorescence the late Dr. William Allen Miller pointed to the lime-light as an illustration of exalted refrangibility. Direct experiments have since entirely confirmed the view expressed at page 210 of his work on 'Chemistry' published in 1855.

became red-hot. No sensible damage was done to the eye by this experiment; no impression of light was produced; the optic nerve was not even conscious of heat.

But the humours of the eye are known to be highly impervious to the invisible calorific rays, and the question therefore arises, 'Did the radiation in the foregoing experiment reach the retina at all?' The answer is, that the rays were in part transmitted to the retina, and in part absorbed by the humours. Experiments on the eye of an ox showed that the proportion of obscure rays which reached the retina amounted to 18 per cent. of the total radiation; while the luminous emission from the electric light amounts to no more than 10 per cent. of the same total. Were the purely luminous rays of the electric lamp converged by our mirror to a focus, there can be no doubt as to the fate of a retina placed there. Its ruin would be inevitable; and yet this would be accomplished by an amount of wave-motion but little more than half of that which the retina bears, without exciting consciousness, at the focus of invisible rays.

This subject will repay a moment's further attention. At a common distance of a foot the visible radiation of the electric light is 800 times the light of a candle. At the same distance, the portion of the radiation of the electric light which reaches the retina, but fails to excite vision, is about 1,500 times the luminous radiation of the candle.[1] But a candle on a clear night can readily be seen at a distance of a mile, its light at this distance being less than $\frac{1}{20,000,000}$ of its light at the distance of a foot. Hence, to make the candle-light a mile off equal in power to the non-luminous radiation received from the electric light at a foot distance, its intensity would have to be multiplied by 1,500 × 20,000,000, or by thirty-thousand millions. Thus the thirty thousand millionth part of the invisible radiation from the electric light, received by the retina at the distance of a foot, would, if slightly changed in character, be amply sufficient to provoke vision. Nothing could more forcibly illustrate that special relationship supposed by Melloni and others to subsist between the optic nerve and the oscillating periods of luminous bodies. The optic nerve responds, as it were, to the waves with which it is in consonance, while it refuses to be excited by others of almost infinitely greater energy, whose periods of recurrence are not in unison with its own.

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[1] It will be borne in mind that the heat which any ray, luminous or non-luminous, is competent to generate is the true measure of the energy of the ray.

10. *Persistence of Rays.*

At an early part of this lecture it was affirmed, that when a platinum wire was gradually raised to a state of high incandescence, new rays were constantly added, while the intensity of the old ones was increased. Thus, in Dr. Draper's experiments, the rise of temperature that *generated* the orange, yellow, green, and blue *augmented* the intensity of the red. What is true of the red is true of every other ray of the spectrum, visible and invisible. We cannot indeed *see* the augmentation of intensity in the region beyond the red, but we can measure it and express it numerically. With this view the following experiment was performed: A spiral of platinum wire was surrounded by a small glass globe to protect it from currents of air; through an orifice in the globe the rays could pass from the spiral and fall afterwards upon a thermo-electric pile. Placing in front of the orifice an opaque solution of iodine, the platinum was gradually raised from a low dark heat to the fullest incandescence, with the following results:—

Appearance of spiral	Energy of obscure radiation
Dark	1
Dark, but hotter	3
Dark, but still hotter	5
Dark, but still hotter	10
Feeble red	19
Dull red	25
Red	37
Full red	62
Orange	89
Bright orange	144
Yellow	202
White	276
Intense white	440

Thus the augmentation of the electric current, which raises the wire from its primitive dark condition to an intense white heat, exalts at the same time the energy of the obscure radiation, until at the end it is fully 440 times what it was at the beginning.

What has been here proved true of the totality of the ultra-red rays is true for each of them singly. Placing our linear thermo-electric pile in any part of the ultra-red spectrum, it may be proved that a ray once emitted continues to be emitted with increased energy as the temperature is augmented. The platinum spiral, so often referred to, being raised to whiteness by an electric current, a brilliant spectrum was formed from its light. A linear thermo-electric pile was placed in the region of obscure rays beyond the red, and by diminishing the current the spiral was reduced to a low temperature. It was then caused to pass through various degrees of darkness and incandescence, with the following results :—

Appearance of spiral	Energy of obscure rays
Dark	1
Dark	6
Faint red	10
Dull red	13
Red	18

Appearance of spiral	Energy of obscure rays
Full red	27
Orange	60
Yellow	93
White	122

Here, as in the former case, the dark and bright radiations reached their maximum together; as the one augmented, the other augmented, until at last the energy of the obscure rays of the particular refrangibility here chosen, became 122 times what it was at first. To reach a white heat the wire has to pass through all the stages of invisible radiation, and in its most brilliant condition it embraces, in an intensified form, the rays of all those stages.

And thus it is with all other kinds of matter, as far as they have hitherto been examined. Coke, whether brought to a white heat by the electric current, or by the oxyhydrogen jet, pours out invisible rays with augmented energy, as its light is increased. The same is true of lime, bricks, and other substances. It is true of all metals which are capable of being heated to incandescence. It also holds good for phosphorus burning in oxygen. Every gush of dazzling light has associated with it a gush of invisible radiant heat, which far transcends the light in energy. This condition of things applies to all bodies capable of being raised to a white heat, either in the solid or the molten condition. It would doubtless also apply to the luminous fogs formed by the condensation of incandescent vapours. In such cases when the curve representing the radiant energy of the body is constructed, the obscure radiation towers upwards like a mountain, the luminous radiation resembling a mere spur at its base. From the very brightness of the light of some of the fixed stars we may infer the intensity of that dark radiation, which is the precursor and inseparable associate of their luminous rays.

We thus find the luminous radiation appearing when the radiant body has attained a certain temperature; or, in other words, when the vibrating atoms of the body have attained a certain width of swing. In solid and molten bodies a certain amplitude cannot be surpassed without the introduction of periods of vibration, which provoke the sense of vision. How are we to figure this? If permitted to speculate, we might ask, are not these more rapid vibrations the progeny of the slower? Is it not really the mutual action of the atoms, when they swing through very wide spaces, and thus encroach upon each other, that causes them to tremble in quicker periods? If so, whatever be the agency by which the large swinging space is obtained, we shall have light-giving vibrations associated with it. It matters not whether the large amplitudes be produced by the strokes of a hammer, or by the blows of the molecules of a non-luminous gas, such as the air at some height above a gas-flame; or by the shock of the aether particles when transmitting radiant heat. The result in all cases will be incandescence. Thus, the invisible waves of our filtered electric beam may be regarded as generating synchronous vibrations among the atoms of the platinum on which they impinge; but, once these vibrations have attained a certain amplitude, the mutual jostling of the atoms produces quicker tremors, and the light-giving waves follow as the necessary product of the heat-giving ones.

11. *Absorption of Radiant Heat by Vapours and Odours.*

We commenced the demonstrations brought forward in this lecture by experiments on permanent gases, and we have now to turn our attention to the vapours of volatile liquids. Here, as in the case of the gases, vast differences have been proved to exist between various kinds of molecules, as regards their power of intercepting the calorific waves. While some vapours allow the waves a comparatively free passage, the minutest bubble of other vapours, introduced into the tube already employed for gases, causes a deflection of the magnetic needle. Assuming the absorption effected by air, at a pressure of one atmosphere, to be unity, the following are the absorptions effected by a series of vapours at a pressure of $\frac{1}{60}$th of an atmosphere:—

Name of vapour	Absorption
Bisulphide of carbon	47
Iodide of methyl	115
Benzol	136
Amylene	321
Sulphuric ether	440
Formic ether	548
Acetic ether	612

Bisulphide of carbon is the most transparent vapour in this list; and acetic ether the most opaque; $\frac{1}{60}$th of an atmosphere of the former, however, produces 47 times the effect of a whole atmosphere of air, while $\frac{1}{60}$th of an atmosphere of the latter produces 612 times the effect of a whole atmosphere of air. Reducing dry air to the pressure of the acetic ether here employed, and comparing them then together, the quantity of wave-motion intercepted by the ether would be many thousand times that intercepted by the air.

Any one of these vapours discharged into the free atmosphere, in front of a body emitting obscure rays, intercepts more or less of the radiation. A similar effect is produced by perfumes diffused in the air, though their attenuation is known to be almost infinite. Carrying, for example, a current of dry air over bibulous paper, moistened by patchouli, the scent taken up by the current absorbs 30 times the quantity of heat intercepted by the air which carries it; and yet patchouli acts more feebly on radiant heat than any other perfume yet examined. Here follow the results obtained with various essential oils, the odour, in each case, being carried by a current of dry air into the tube already employed for gases and vapours:—

Name of perfume	Absorption
Patchouli	30
Sandal wood	32
Geranium	33
Oil of cloves	34
Otto of roses	37
Bergamot	44
Neroli	47
Lavender	60
Lemon	65
Portugal	67
Thyme	68
Rosemary	74
Oil of laurel	80
Camomile flowers	87
Cassia	109
Spikenard	355
Aniseed	372

Thus the absorption by a tube full of dry air being 1, that of the odour of patchouli diffused in it is 30, that of lavender 60, that of rosemary 74, whilst that of aniseed amounts to 372. It would be idle to speculate on the quantities of matter concerned in these actions.

12. *Aqueous Vapour in relation to the Terrestrial Temperatures.*

We are now fully prepared for a result which, without such preparation, might appear incredible. Water is, to some extent, a *volatile body*, and our atmosphere, resting as it does upon the surface of the ocean, receives from it a continual supply of aqueous vapour. It would be an error to confound clouds or fog or any visible mist with the vapour of water: this vapour is a perfectly impalpable gas, diffused, even on the clearest days, throughout the atmosphere. Compared with the great body of the air, the aqueous vapour it contains is of almost infinitesimal amount, 99½ out of every 100 parts of the atmosphere being composed of oxygen and nitrogen. In the absence of experiment, we should never think of ascribing to this scant and varying constituent any important influence on terrestrial radiation; and yet its influence is far more potent than that of the great body of the air. To say that on a day of average humidity in England, the atmospheric vapour exerts 100 times the action of the air itself, would certainly be an understatement of the fact. The peculiar qualities of this vapour, and the circumstance that at ordinary temperatures it is very near its point of condensation, render the results which it yields in the apparatus already described, less than the truth; and I am not prepared to say that the absorption by this substance is not 200 times that of the air in which it is diffused. Comparing a single molecule of aqueous vapour with an atom of either of the main constituents of our atmosphere, I am not prepared to say how many thousand times the action of the former exceeds that of the latter.

But it must be borne in mind that these large numbers depend, in part, on the extreme feebleness of the air; the power of aqueous vapour seems vast, because that of the air with which it is compared is infinitesimal. Absolutely considered, however, this substance, notwithstanding its small specific gravity, exercises a very potent action. Probably from 10 to 15 per cent. of the heat radiated from the earth is absorbed within 10 or 20 feet of the earth's surface. This must evidently be of the utmost consequence to the life of the world. Imagine the superficial molecules of the earth trembling with the motion of heat, and imparting it to the surrounding aether; this motion would be carried rapidly away, and lost for ever to our planet, if the waves of aether had nothing but the air to contend with in their outward course. But the aqueous vapour takes up the motion of the aethereal waves, and becomes thereby heated, thus wrapping the earth like a warm garment, and protecting its surface from the deadly chill which it would otherwise sustain. Various philosophers have speculated on the influence of an atmospheric envelope. De Saussure, Fourier, M. Pouillet and Mr. Hopkins have, one and all, enriched scientific literature with contributions on this subject, but the considerations which these eminent men have applied to atmospheric air, have, if my experiments be correct, to be transferred to the aqueous vapour.

The observations of meteorologists furnish important, though hitherto unconscious, evidence of the influence of this agent. Wherever the air is dry we are liable to daily extremes of temperature. By day, in such places, the sun's heat reaches the earth unimpeded, and renders the maximum high; by night, on the other hand, the earth's heat escapes unhindered into space, and renders the minimum low. Hence the difference between the maximum and minimum is greatest where the air is driest. In the plains of India, on the heights of the Himalaya, in central Asia, in Australia—wherever drought reigns, we have the heat of day forcibly contrasted with the chill of night. In the Sahara itself, when the sun's rays cease to impinge on the burning soil, the temperature runs rapidly down to freezing, because there is no vapour overhead to check the calorific drain. And here another instance might be added to the numbers already known, in which nature tends as it were to check her own excess. By nocturnal refrigeration, the aqueous vapour of the air is condensed to water on the surface of the earth; and, as only the superficial portions radiate, the act of condensation makes water the radiating body. Now experiment proves that to the rays emitted by water, aqueous vapour is especially opaque. Hence the very act of condensation, consequent on terrestrial cooling, becomes a safeguard to the earth, imparting to its radiation that particular character which renders it most liable to be prevented from escaping into space.

It might however be urged that, inasmuch as we derive all our heat from the sun, the selfsame covering which protects the earth from chill must also shut out the solar radiation. This is partially true, but only partially; the sun's rays are different in quality from the earth's rays, and it does not at all follow that the substance which absorbs the one must necessarily absorb the other. Through a layer of water, for example, one tenth of an inch in thickness, the sun's rays are transmitted with comparative freedom; but through a layer half this thickness, as Melloni has proved, no single ray from the warmed earth could pass. In like manner, the sun's rays pass with comparative freedom through the aqueous vapour of the air: the absorbing power of this substance being mainly exerted upon the heat that endeavours to escape from the earth. In consequence of this differential action upon solar and terrestrial heat, the mean temperature of our planet is higher than is due to its distance from the sun.

13. *Liquids and their Vapours in relation to Radiant Heat.*

The deportment here assigned to atmospheric vapour has been established by direct experiments on air taken from the streets and parks of London, from the downs of Epsom, from the hills and sea-beach of the Isle of Wight, and also by experiments on air in the first instance dried, and afterwards rendered artificially humid by pure distilled water. It has also been established in the following way: Ten volatile liquids were taken at random and the power of these liquids, at a common thickness, to intercept the waves of heat, was carefully determined. The vapours of the liquids were next taken, in quantities proportional to the quantities of liquid, and the power of the vapours to intercept the waves of heat was also determined. Commencing with the substance which exerted the least absorptive power, and proceeding onwards to the most energetic, the following order of absorption was observed:—

Liquids	Vapours
Bisulphide of carbon.	Bisulphide of carbon.
Chloroform.	Chloroform.
Iodide of methyl.	Iodide of methyl.
Iodide of ethyl.	Iodide of ethyl.
Benzol.	Benzol.
Amylene.	Amylene.
Sulphuric ether.	Sulphuric ether.
Acetic ether.	Acetic ether.
Formic ether.	Formic ether.
Alcohol.	Alcohol.
Water.	

We here find the order of absorption in both cases to be the same. We have liberated the molecules from the bonds which trammel them more or less in a liquid condition; but this change in their state of aggregation does not change their relative powers of absorption. Nothing could more clearly prove that the act of absorption depends upon the individual molecule, which equally asserts its power in the liquid and the gaseous state. We may assuredly conclude from the above table that the position of a vapour is determined by that of its liquid. Now at the very foot of the list of liquids stands *water*, signalising itself above all others by its enormous power of absorption. And from this fact, even if no direct experiment on the vapour of water had ever been made, we should be entitled to rank that vapour as our most powerful absorber of radiant heat. Its attenuation, however, diminishes its action. It has been proved that a shell of air two inches in thickness surrounding our planet, and saturated with the vapour of sulphuric ether, would intercept 35 per cent. of the earth's radiation. And though the quantity of aqueous vapour necessary to saturate air is much less than the amount of sulphuric ether vapour which it can sustain, it is still extremely probable that the estimate already made of the action of atmospheric vapour within 10 feet of the earth's surface, is under the mark; and that we are indebted to this wonderful substance, to an extent not accurately determined, but certainly far beyond what has hitherto been imagined, for the temperature now existing at the surface of the globe.

14. *Reciprocity of Radiation and Absorption.*

Throughout the reflections which have hitherto occupied us, the image before the mind has been that of a radiant source generating calorific waves, which on passing among the scattered molecules of a gas or vapour were intercepted by those molecules in various degrees. In all cases it was the transference of motion from the aether to the comparatively quiescent molecules of the gas or vapour. We have now to change the form of our conception, and to figure these molecules not as absorbers but as radiators, not as the recipients but as the originators of wave-motion. That is to say, we must figure them vibrating, and generating in the surrounding aether undulations which speed through it with the velocity of light. Our object now is to enquire whether the act of chemical combination, which proves so potent as regards the phenomena of absorption, does not also manifest its power in the phenomena of radiation. For the examination of this question it is necessary, in the first place, to heat our gases and vapours to the same temperature, and then examine their power of discharging the motion thus imparted to them upon the aether in which they swing.

A heated copper ball was placed above a ring gas-burner, possessing a great number of small apertures, the burner being connected by a tube with vessels containing the various gases to be examined. By gentle pressure the gases were forced through the orifices of the burner against the copper ball, where each of them, being heated, rose in an ascending column. A thermo-electric pile, entirely screened off from the hot ball, was exposed to the radiation of the warm gas, and while deflection of a magnetic needle connected with the pile declared the energy of the radiation.

By this mode of experiment it was proved that the selfsame molecular arrangement which renders a gas a powerful absorber, renders it in the same degree a powerful radiator—that the atom or molecule which is competent to intercept the calorific waves is, in the same degree, competent to generate them. Thus, while the atoms of elementary gases proved themselves unable to emit any sensible amount of radiant heat, the molecules of compound gases were shown to be capable of powerfully disturbing the surrounding aether. By special modes of experiment the same was proved to hold good for the vapours of volatile liquids, the radiative power of every vapour being found proportional to its absorptive power.

The method of experiment here pursued, though not of the simplest character, is still within your grasp. When air is permitted to rush into an exhausted tube, the temperature of the air is raised to a degree equivalent to the *vis viva* extinguished.[1] Such air is said to be dynamically heated, and, if pure, it shows itself incompetent to radiate, even when a rock-salt window is provided for the passage of its rays. But if instead of being empty the tube contain a small quantity of vapour, then the warmed air will communicate heat by contact to the vapour, which will be thus enabled to radiate. Thus the molecules of the vapour convert into the radiant form the heat imparted dynamically to the atoms of the air. By this process, which I have called Dynamic Radiation, the radiative power of both vapours and gases has been determined, and the reciprocity of their radiation and absorption proved.[2]

In the excellent researches of Leslie, De la Provostaye and Desains, and Balfour Stewart, the reciprocity of radiation and absorption, as regards solid bodies, has been variously illustrated; while the labours, theoretical and experimental, of Kirchhoff have given this subject a wonderful expansion, and enriched it by applications of the highest kind. To their results are now to be added the foregoing, whereby gases and vapours, which have been hitherto thought inaccessible to experiments of this kind, are proved to exhibit the duality of radiation and absorption, the influence of chemical combination on both being exhibited in the most decisive and extraordinary way.

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[1] See page 14 for a definition of *vis viva*.

[2] When heated air imparts its motion to another gas or vapour, the transference of heat is accompanied by a change of vibrating period. The Dynamic Radiation of vapours is rendered possible by the transmutation of vibrations.

15. *Influence of Vibrating Period and Molecular Form. Physical Analysis of the Human Breath.*

In the foregoing experiments with gases and vapours we have employed throughout invisible rays: some of these bodies are so impervious, that in lengths of a few feet only they intercept every ray as effectually as a layer of pitch would do. The substances, however, which show themselves thus opaque to radiant heat are perfectly transparent to light. Now the rays of light differ from those of invisible heat, only in point of period, the former failing to affect the retina because their periods of recurrence are too slow. Hence, in some way or other the transparency of our gases and vapours depends upon the periods of the waves which impinge upon them. What is the nature of this dependence? The admirable researches of Kirchhoff help us to an answer. The atoms and molecules of every gas have certain definite rates of oscillation, and those waves of aether are most copiously absorbed whose periods of recurrence synchronise with the periods of the molecules amongst which they pass. Thus, when we find the invisible rays absorbed and the visible ones transmitted by a layer of gas, we conclude that the oscillating periods of the gaseous molecules coincide with those of the invisible, and not with those of the visible spectrum.

It requires some discipline of the imagination to form a clear picture of this process. Such a picture is, however, possible, and ought to be obtained. When the waves of aether impinge upon molecules whose periods of vibration coincide with the recurrence of the undulations, the timed strokes of the waves, the vibration of the molecules augments, as a heavy pendulum is set in motion by well-timed puffs of breath. Millions of millions of shocks are received every second from the calorific waves; and it is not difficult to see that as every wave arrives just in time to repeat the action of its predecessor, the molecules must finally be caused to swing through wider spaces than if the arrivals were not so timed. In fact, it is not difficult to see that an assemblage of molecules, operated upon by contending waves, might remain practically quiescent. This is actually the case when the waves of the visible spectrum pass through a transparent gas or vapour. There is here no sensible transference of motion from the aether to the molecules; in other words, there is no sensible absorption of heat.

One striking example of the influence of period may be here recorded. Carbonic acid gas is one of the feeblest of absorbers of the radiant heat emitted by solid sources. It is, for example, to a great extent transparent to the rays emitted by the heated copper plate already referred to. There are, however, certain rays, comparatively few in number, emitted by the copper, to which the carbonic acid is impervious; and could we obtain a source of heat emitting such rays only, we should find carbonic acid more opaque to the radiation from that source, than any other gas. Such a source is actually found in the flame of carbonic oxide, where hot carbonic acid constitutes the main radiating body. Of the rays emitted by our heated plate of copper, olefiant gas absorbs ten times the quantity absorbed by carbonic acid. Of the rays emitted by a carbonic oxide flame, carbonic acid absorbs twice as much as olefiant gas. This wonderful change in the power of the former, as an absorber, is simply due to the fact, that the periods of the hot and cold carbonic acid are identical, and that the waves from the flame freely transfer their motion to the molecules which synchronise with them. Thus it is that the tenth of an atmosphere of carbonic acid, enclosed in a tube four feet long, absorbs 60 per cent. of the radiation from a carbonic oxide flame, while one-thirtieth of an atmosphere absorbs 48 per cent. of the heat from the same origin.

In fact, the presence of the minutest quantity of carbonic acid may be detected by its action on the rays from the carbonic oxide flame. Carrying, for example, the dried human breath into a tube four feet long, the absorption there effected by the carbonic acid of the breath amounts to 50 per cent. of the entire radiation. Radiant heat may indeed be employed as a means of determining practically the amount of carbonic acid expired from the lungs. My late assistant, Mr. Barrett, while under my direction, made this determination. The absorption produced by the breath freed from its moisture, but retaining its carbonic acid, was first determined. Carbonic acid, artificially prepared, was then mixed with dry air in such proportions that the action of the mixture upon the rays of heat was the same as that of the dried breath. The percentage of the former being known, immediately gave that of the latter. The same breath analysed chemically by Dr. Frankland, and physically by Mr. Barrett, gave the following results:—

Percentage of Carbonic Acid in the Human Breath.

Chemical analysis	Physical analysis
4·66	4·56
5·33	5·22

It is thus proved that in the quantity of aethereal motion which it is competent to take up, we have a practical measure of the carbonic acid of the breath, and hence of the combustion going on in the human lungs.

Still this question of period, though of the utmost importance, is not competent to account for the whole of the observed facts. The aether, as far as we know, accepts vibrations of all periods with the same readiness. To it the oscillations of an atom of oxygen are just as acceptable as those of a molecule of olefiant gas; that the vibrating oxygen then stands so far below the olefiant gas in radiant power must be referred not to period, but to some other peculiarity of the elementary gas. The atomic group which constitutes the molecule of olefiant gas, produces many thousand times the disturbance caused by the oxygen, because the group is able to lay a vastly more powerful hold upon the aether than the single atoms can. The cavities and indentations of a molecule composed of spherical atoms may be one cause of this augmented hold. Another, and probably very potent one may be, that the vibrations, being those of the constituent atoms of the molecule, are generated in highly condensed aether, which acts like condensed air upon sound. But whatever may be the fate of these attempts to visualise the physics of the process, it will still remain true, that to account for the phenomena of radiation and absorption we must take into consideration the shape, size, and condition of the aether within the molecules, by which the aether is disturbed.

16. *Summary and Conclusion.*

Let us now cast a momentary glance over the ground that we have left behind. The general nature of light and heat was first briefly described: the compounding of matter from elementary atoms, and the influence of the act of combination on radiation and absorption, were considered and experimentally illustrated. Through the transparent elementary gases radiant heat was found to pass as through a vacuum, while many of the compound gases presented almost impassable obstacles to the calorific waves. This deportment of the simple gases directed our attention to other elementary bodies, the examination of which led to the discovery that the element iodine, dissolved in bisulphide of carbon, possesses the power of detaching, with extraordinary sharpness, the light of the spectrum from its heat, intercepting all luminous rays up to the extreme red, and permitting the calorific rays beyond the red to pass freely through it. This substance was then employed to filter the beams of the electric light, and to form foci of invisible rays so intense as to produce almost all the effects obtainable in an ordinary fire. Combustible bodies were burnt, and refractory ones were raised to a white heat, by the concentrated invisible rays. Thus, by exalting their refrangibility, the invisible rays of the electric light were rendered visible, and all the colours of the solar spectrum were extracted from utter darkness. The extreme richness of the electric light in invisible rays of low refrangibility was demonstrated, one-eighth only of its radiation consisting of luminous rays. The deadness of the optic nerve to those invisible rays was proved, and experiments were then added to show that the bright and the dark rays of a solid body, raised gradually to intense incandescence, are strengthened together; intense dark heat being an invariable accompaniment of intense white heat. A sun could not be formed, or a meteorite rendered luminous, on any other condition. The light-giving rays constituting only a small fraction of the total radiation, their unspeakable importance to us is due to the fact, that their periods are attuned to the special requirements of the eye.

Among the vapours of volatile liquids vast differences were also found to exist, as regards their powers of absorption. We followed various molecules from a state of liquid to a state of gas, and found, in both states of aggregation, the power of the individual molecules equally asserted. The position of a vapour as an absorber of radiant heat was shown to be determined by that of the liquid from which it is derived. Reversing our conceptions, and regarding the molecules of gases and vapours not as the recipients but as the originators of wave-motion; not as absorbers but as radiators; it was proved that the powers of absorption and radiation went hand in hand, the selfsame chemical act which rendered a body competent to intercept the waves of aether, rendering it competent, in the same degree, to generate them. Perfumes were next subjected to examination, and, notwithstanding their extraordinary tenuity, they were found vastly superior, in point of absorptive power, to the body of the air in which they were diffused. We were led thus slowly up to the examination of the most widely diffused and most important of all vapours—the aqueous vapour of our atmosphere, and we found in it a potent absorber of the purely calorific rays. The power of this substance to influence climate, and its general influence on the temperature of the earth, were then briefly dwelt upon. A cobweb spread above a blossom is sufficient to protect it from nightly chill; and thus the aqueous vapour of our air, attenuated as it is, checks the drain of terrestrial heat, and saves the surface of our planet from the refrigeration which would assuredly accrue, were no such substance interposed between it and the voids of space. We considered the influence of vibrating period, and molecular form, on absorption and radiation, and finally deduced, from its action upon radiant heat, the exact amount of carbonic acid expired by the human lungs.

Thus, in brief outline, were placed before you some of the results of recent enquiries in the domain of Radiation, and my aim throughout has been to raise in your minds distinct physical images of the various processes involved in our researches. It is thought by some that natural science has a deadening influence on the imagination, and a doubt might fairly be raised as to the value of any study which would necessarily have this effect. But the experience of the last hour must, I think, have convinced you, that the study of natural science goes hand in hand with the culture of the imagination. Throughout the greater part of this discourse we have been sustained by this faculty. We have been picturing atoms, and molecules, and vibrations, and waves, which eye has never seen nor ear heard, and which can only be discerned by the exercise of imagination. This, in fact, is the faculty which enables us to transcend the boundaries of sense, and connect the phenomena of our visible world with those of an invisible one. Without imagination we never could have risen to the conceptions which have occupied us here to-day; and in proportion to your power of exercising this faculty aright, and of associating definite mental images with the terms employed, will be the pleasure and the profit which you will derive from this lecture. The outward facts of nature are insufficient to satisfy the mind. We cannot be content with knowing that the light and heat of the sun illuminate and warm the world. We are led irresistibly to enquire, 'What is light, and what is heat?' and this question leads us at once out of the region of sense into that of imagination.

Thus pondering, and questioning, and striving to supplement that which is felt and seen, but which is incomplete, by something unfelt and unseen which is necessary to its completeness, men of genius have in part discerned, not only the nature of light and heat, but also, through them, the general relationship of natural phenomena. The working power of Nature is the power of actual or potential motion, of which all its phenomena are but special forms. This motion manifests itself in tangible and in intangible matter, being incessantly transferred from the one to the other, and incessantly transformed by the change. It is as real in the waves of the aether as in the waves of the sea; the latter—derived as they are from winds, which in their turn are derived from the sun—are, indeed, nothing more than the heaped-up motion of the former. It is the calorific waves emitted by the sun which heat our air, produce our winds, and hence agitate our ocean. And whether they break in foam upon the shore, or rub silently against the ocean's bed, or subside by the mutual friction of their own parts, the sea waves, which cannot subside without producing heat, finally resolve themselves into waves of aether, thus regenerating the motion from which their temporary existence was derived. This connection is typical. Nature is not an aggregate of independent parts, but an organic whole. If you open a piano and sing into it, a certain string will respond. Change the pitch of your voice; the first string ceases to vibrate, but another replies. Change again the pitch; the first two strings are silent, while another resounds. Now in altering the pitch you simply change the form of the motion communicated by your vocal chords to the air, one string responding to one form, and another to another. And thus is sentient man acted on by Nature, the optic, the auditory, and other nerves of the human body being so many strings differently tuned, and responsive to different forms of the universal power.

III.

ON RADIANT HEAT IN RELATION TO THE COLOUR AND CHEMICAL CONSTITUTION OF BODIES.

1866.

ONE of the most important functions of physical science, considered as a discipline of the mind, is to enable us by means of the tangible processes of Nature to apprehend the intangible. The tangible processes give *direction* to the line of thought; but this once given, the length of the line is not limited by the boundaries of the senses. Indeed, the domain of the senses, in Nature, is almost infinitely small in comparison with the vast region accessible to thought which lies beyond them. From a few observations of a comet, when it comes within the range of his telescope, an astronomer can calculate its path in regions which no telescope can reach: and in like manner, by means of data furnished in the narrow world of the senses, we make ourselves at home in other and wider worlds, which can be traversed by the intellect alone.

From the earliest ages the questions, 'What is light?' and 'What is heat?' have occurred to the minds of men; but these questions never would have been answered had they not been preceded by the question, 'What is sound?' Amid the grosser phenomena of acoustics the mind was first disciplined, conceptions being thus obtained from direct observation, which were afterwards applied to phenomena of a character far too subtle to be observed directly. Sound we know to be due to vibratory motion. A vibrating tuning-fork, for example, moulds the air around it into undulations or waves, which speed away on all sides with a certain measured velocity, impinge upon the drum of the ear, shake the auditory nerve, and awake in the brain the sensation of sound. When sufficiently near a sounding body we can feel the vibrations of the air. A deaf man, for example, plunging his hand into a bell when it is sounded, feels through the common nerves of his body those tremors which, when imparted to the nerves of healthy ears, are translated into sound. There are various ways of rendering those sonorous vibrations not only tangible but visible; and it was not until numberless experiments of this kind had been executed, that the scientific investigator abandoned himself wholly, and without a shadow of misgiving, to the conviction that what is sound within us is, outside of us, a motion of the air.

But once having established this fact—once having proved beyond all doubt that the sensation of sound is produced by an agitation of the nerve of the ear—the thought soon suggested itself that light might be due to an agitation of the nerve of the eye. This was a great step in advance of that ancient notion which regarded light as something emitted by the eye, and not as anything imparted to it. But if light be produced by an agitation of the optic nerve or retina, what is it that produces the agitation? Newton, you know, supposed minute particles to be shot through the humours of the eye against the retina, which he supposed to hang like a target at the back of the eye. The impact of these particles against the target, Newton believed to be the cause of light. But Newton's notion has not held its ground, being entirely driven from the field by the more wonderful and far more philosophical notion that light, like sound, is a product of wave-motion.

The domain in which this motion of light is carried on lies entirely beyond the reach of our senses. The waves of light require a medium for their formation and propagation; but we cannot see, or feel, or taste, or smell this medium. How, then, has its existence been established? By showing, that by the assumption of this wonderful intangible *aether*, all the phenomena of optics are accounted for, with a fulness, and clearness, and conclusiveness, which leave no desire of the intellect unsatisfied. When the law of gravitation first suggested itself to the mind of Newton, what did he do? He set himself to examine whether it accounted for all the facts. He determined the courses of the planets; he calculated the rapidity of the moon's fall towards the earth; he considered the precession of the equinoxes, the ebb and flow of the tides, and found all explained by the law of gravitation. He therefore regarded this law as established, and the verdict of science subsequently confirmed his conclusion. On similar, and, if possible, on stronger grounds, we found our belief in the existence of the universal aether. It explains facts far more various and complicated than those on which Newton based his law. If a single phenomenon could be pointed out which the aether is proved incompetent to explain, we should have to give it up; but no such phenomenon has ever been pointed out. It is, therefore, at least as certain that space is filled with a medium, by means of which suns and stars diffuse their radiant power, as that it is traversed by that force which holds in its grasp, not only our planetary system, but the immeasurable heavens themselves.

There is no more wonderful instance than this of the production of a line of thought, from the world of the senses into the region of pure imagination. I mean by imagination here, not that play of fancy which can give to airy nothings a local habitation and a name, but that power which enables the mind to conceive realities which lie beyond the range of the senses—to present to itself distinct images of processes which, though mighty in the aggregate beyond all conception, are so minute individually as to elude all observation. It is the waves of air excited by a tuning-fork which render its vibrations audible. It is the waves of aether sent forth from those lamps overhead which render them luminous to us; but so minute are these waves, that it would take from 30,000 to 60,000 of them placed end to end to cover a single inch. Their number, however, compensates for their minuteness. Trillions of them have entered your eyes, and hit the retina at the back of the eye, in the time consumed in the utterance of the shortest sentence of this discourse. This is the steadfast result of modern research; but we never could have reached it without previous discipline. We never could have measured the waves of light, nor even imagined them to exist, had we not previously exercised ourselves among the waves of sound. Sound and light are now mutually helpful, the conceptions of each being expanded, strengthened, and defined by the conceptions of the other.

The aether which conveys the pulses of light and heat not only fills celestial space, swathing suns, and planets, and moons, but it also encircles the atoms of which these bodies are composed. It is the motion of these atoms, and not that of any sensible parts of bodies, that the aether conveys; it is this motion that constitutes the objective cause of what, in our sensations, are light and heat. An atom, then, sending its pulses through the aether, resembles a tuning-fork sending its pulses through the air. Let us look for a moment at this thrilling medium, and briefly consider its relation to the bodies whose vibrations it conveys. Different bodies, when heated to the same temperature, possess very different powers of agitating the aether: some are good radiators, others are *bad radiators*; which means that some are so constituted as to communicate their motion freely to the aether, producing therein powerful undulations; while others are unable thus to communicate their motion, but glide through the medium without materially disturbing its repose. Recent experiments have proved that elementary bodies, except under certain anomalous conditions, belong to the class of bad radiators. An atom, vibrating in the aether, resembles a naked tuning-fork vibrating in the air. The amount of motion communicated to the air by the thin prongs is too small to evoke at any distance the sensation of sound. But if we permit the atoms to combine chemically and form molecules, the result, in many cases, is an enormous change in the power of radiation. The amount of aethereal disturbance, produced by the combined atoms of a body, may be many thousand times that produced by its constituent atoms when uncombined. The effect is roughly typified by a tuning-fork when connected with its resonant case. The fork and its case swing as a compound system, and the vibrations which were before inaudible, are now the source of a musical sound so powerful, that it might be plainly heard by thousands at once. The fork and its case combined may be roughly regarded as a good radiator of sound.

The pitch of a musical note depends upon the rapidity of its vibrations, or, in other words, on the length of its waves. Now, the pitch of a note answers to the colour of light. Taking a slice of white light from the sun, or from an electric lamp, and causing the light to pass through an arrangement of prisms, it is decomposed. We have the effect obtained by Newton, who first unrolled the solar beam into the splendours of the solar spectrum. At one end of this spectrum we have red light, at the other, violet; and between those extremes lie the other prismatic colours. As we advance along the spectrum from the red to the violet, the pitch of the light—if I may use the expression—heightens, the sensation of violet being produced by a more rapid succession of impulses than that which produces the impression of red. The vibrations of the violet are about twice as rapid as those of the red; in other words, the range of the visible spectrum is about an octave.

There is no solution of continuity in this spectrum; one colour changes into another by insensible gradations. It is as if an infinite number of tuning-forks, of gradually augmenting pitch, were vibrating at the same time. But turning to another spectrum—that, namely, obtained from the incandescent vapour of silver—you observe that it consists of two narrow and intensely luminous green bands. Here it is as if two forks only, of slightly different pitch, were vibrating. The length of the waves which produce this first band is such that 47,460 of them, placed end to end, would fill an inch. The waves which produce the second band are a little shorter; it would take of these 47,920 to fill an inch. In the case of the first band, the number of impulses imparted, in one second, to every eye which sees it, is 577 millions of millions; while the number of impulses imparted, in the same time, by the second band is 600 millions of millions. We may project upon a white screen the beautiful stream of green light from which these bands were derived. This luminous stream is the incandescent vapour of silver. The rates of vibration of the atoms of that vapour are as rigidly fixed as those of two tuning-forks; and to whatever height the temperature of the vapour may be raised, the rapidity of its vibrations, and consequently its colour, which wholly depends upon that rapidity, remain unchanged.

The vapour of water, as well as the vapour of silver, has its definite periods of vibration, and these are such as to disqualify the vapour, when acting freely as such, from being raised to a white heat. The oxyhydrogen flame, for example, consists of hot aqueous vapour. It is scarcely visible in the air of this room, and it would be still less visible if we could burn the gas in a clean atmosphere. But the atmosphere, even at the summit of Mont Blanc, is dirty; in London it is more than dirty; and the burning dirt gives to this flame the greater portion of its present light. But the heat of the flame is enormous. Cast iron fuses at a temperature of 2,000° Fahr.; while the temperature of the oxyhydrogen flame is 6,000° Fahr. A piece of platinum is heated to vivid redness, at a distance of two inches beyond the visible termination of the flame. The vapour which produces incandescence is here absolutely dark. In the flame itself the platinum is raised to dazzling whiteness, and is even pierced by the flame. When this flame impinges on a piece of lime, we have the dazzling Drummond light. But the light is here due to the fact that when it impinges upon the solid body, the vibrations excited in that body by the flame are of periods different from its own.

Thus far we have fixed our attention on atoms and molecules in a state of vibration, and surrounded by a medium which accepts their vibrations, and transmits them through space. But suppose the waves generated by one system of molecules to impinge upon another system, how will the waves be affected? Will they be stopped, or will they be permitted to pass? Will they transfer their motion to the molecules on which they impinge, or will they glide round the molecules, through the intermolecular spaces, and thus escape?

The answer to this question depends upon a condition which may be beautifully exemplified by an experiment on sound. These two tuning-forks are tuned absolutely alike. They vibrate with the same rapidity, and, mounted thus upon their resonant cases, you hear them loudly sounding the same musical note. Stopping one of the forks, I throw the other into strong vibration, and bring that other near the silent fork, but not into contact with it. Allowing them to continue in this position for four or five seconds, and then stopping the vibrating fork, the sound has not ceased. The second fork has taken up the vibrations of its neighbour, and is now sounding in its turn. Dismounting one of the forks, and permitting the other to remain upon its stand, I throw the dismounted fork into strong vibration. You cannot hear it sound. Detached from its stand, the amount of motion which it can communicate to the air is too small to be sensible at any distance. When the dismounted fork is brought close to the mounted one, but not into actual contact with it, out of the silence rises a mellow sound. Whence comes it? From the vibrations which have been transferred from the dismounted fork to the mounted one.

That the motion should thus transfer itself through the air it is necessary that the two forks should be in perfect unison. If a morsel of wax not larger than a pea be placed on one of the forks, it is rendered thereby powerless to affect, or to be affected by, the other. It is easy to understand this experiment. The pulses of the one fork can affect the other, because they are *perfectly timed*. A single pulse causes the prong of the silent fork to vibrate through an infinitesimal space. But just as it has completed this small vibration, another pulse is ready to strike it. Thus, the impulses add themselves together. In the five seconds during which the forks were held near each other, the vibrating fork sent 1,280 waves against its neighbour, and those 1,280 shocks, all delivered at the proper moment, all, as I have said, perfectly timed, have given such strength to the vibrations of the mounted fork as to render them audible to all.

Another curious illustration of the influence of synchronism on musical vibrations, is this: Three small gas-flames are inserted into three glass tubes of different lengths. Each of these flames can be caused to emit a musical note, the pitch of which is determined by the length of the tube surrounding the flame. The shorter the tube the higher is the pitch. The flames are now silent within their respective tubes, but each of them can be caused to respond to a proper note sounded anywhere in this room. With an instrument called a syren, a powerful musical note, of increasing pitch, can be produced. Beginning with a note of low pitch, and ascending gradually to a higher one, we finally attain the note of the flame in the longest tube. The moment it is reached, the flame bursts into song. The other flames are still silent within their tubes. But by urging the instrument on to higher notes, the second flame is started, and the third alone remains. A still higher note starts it also. Thus, as the sound of the syren rises gradually in pitch, it awakens every flame in passing, by striking it with a series of waves whose periods of recurrence are similar to its own.

Now the wave-motion from the syren is in part taken up by the flame which synchronises with the waves; and had these waves to impinge upon a multitude of flames, instead of upon one flame only, the transference might be so great as to absorb the whole of the original wave-motion. Let us apply these facts to radiant heat. This blue flame is the flame of carbonic oxide; this transparent gas is carbonic acid gas. In the blue flame we have carbonic acid intensely heated, or, in other words, in a state of intense vibration. It thus resembles the sounding fork, while this cold carbonic acid resembles the silent one. What is the consequence? Through the synchronism of the hot and cold gas, transmission of the radiant heat of the former through the latter is prevented. The cold gas is intensely opaque to the radiation from this particular flame, though highly transparent to heat of every other kind. We are here manifestly dealing with that great principle which lies at the basis of spectrum analysis, and which has enabled scientific men to determine the substances of which the sun, the stars, and even the nebulæ are composed: the principle, namely, that a body which is competent to emit any ray, whether of heat or light, is competent in the same degree to absorb that ray. The absorption depends on the synchronism existing between the vibrations of the atoms from which the rays, or more correctly the *waves*, issue, and those of the atoms on which they impinge.

To its incompetence to emit white light, aqueous vapour adds incompetence to absorb white light. It cannot, for example, absorb the luminous rays of the sun, though it can absorb the non-luminous rays of the earth. This incompetence of the vapour to absorb luminous rays is shared by water and ice—in fact, by all really transparent substances. Their transparency is due to their inability to absorb luminous rays. The molecules of such substances are in dissonance with the luminous waves; and hence such waves pass through transparent bodies without disturbing the molecular rest. A purely luminous beam, however intense may be its heat, is sensibly incompetent to melt the smallest particle of ice. We can, for example, converge a powerful luminous beam upon a surface covered with hoar frost, without melting a single spicula of the ice crystals. How then, it may be asked, are the snows of the Alps swept away by the sunshine of summer? I answer, they are not swept away by sunshine at all, but by rays which have no sunshine whatever in them. The luminous rays of the sun fall upon the snow-fields and are flashed in echoes from crystal to crystal, but they find *next to no* lodgment within the crystals. They are hardly at all absorbed, and hence they cannot produce fusion. But a body of powerful dark rays is emitted by the sun; and it is these that cause the glaciers to shrink and the snows to disappear; it is they that fill the banks of the Arve and Arveyron, and liberate from their frozen captivity the Rhone and the Rhine.

Placing a concave silvered mirror behind the electric light its rays are converged to a focus of dazzling brilliancy. Placing in the path of the rays, between the light and the focus, a vessel of water, and introducing at the focus a piece of ice, the ice is not melted by the concentrated beam. Matches, at the same place, are ignited, and wood is set on fire. The powerful heat, then, of this luminous beam is incompetent to melt the ice. On withdrawing the cell of water, the ice immediately liquefies, and the water trickles from it in drops. Reintroducing the cell of water, the fusion is arrested, and the drops cease to fall. The transparent water of the cell exerts no sensible absorption on the luminous rays, still it withdraws something from the beam, which, when permitted to act, is competent to melt the ice. This something is the dark radiation of the electric light. Again, I place a slab of pure ice in front of the electric lamp; send a luminous beam first through our cell of water and then through the ice. By means of a lens an image of the slab is cast upon a white screen. The beam, sifted by the water, has little power upon the ice. But observe what occurs when the water is removed; we have here a star and there a star, each star resembling a flower of six petals, and growing visibly larger before our eyes. As the leaves enlarge, their edges become serrated, but there is no deviation from the six-rayed type. We have here, in fact, the crystallisation of the ice inverted by the invisible rays of the electric beam. They take the molecules down in this wonderful way, and reveal to us the exquisite atomic structure of the substance with which Nature every winter roofs our ponds and lakes.

Numberless effects, apparently anomalous, might be adduced in illustration of the action of these lightless rays. These two powders, for example, are both white, and undistinguishable from each other by the eye. The luminous rays of the sun are unabsorbed by both—from such rays these powders acquire no heat; still one of them, sugar, is heated so highly by the concentrated beam of the electric lamp, that it first smokes and then violently inflames, while the other substance, salt, is barely warmed at the focus. Placing two perfectly transparent liquids in test-tubes at the focus, one of them boils in a couple of seconds, while the other, in a similar position, is hardly warmed. The boiling-point of the first liquid is 78° C., which is speedily reached; that of the second liquid is only 48° C., which is never reached at all. These anomalies are entirely due to the unseen element which mingles with the luminous rays of the electric beam, and indeed constitutes 90 per cent. of its calorific power.

A substance, as many of you know, has been discovered, by which these dark rays may be detached from the total emission of the electric lamp. This ray-filter is a liquid, black as pitch to the luminous, but bright as a diamond to the non-luminous, radiation. It mercilessly cuts off the former, but allows the latter free transmission. When these invisible rays are brought to a focus, at a distance of several feet from the electric lamp, the dark rays form an invisible image of their source. By proper means, this image may be transformed into a visible one of dazzling brightness. It might, moreover, be shown, if time permitted, how, out of those perfectly dark rays, could be extracted, by a process of transmutation, all the *colours* of the solar spectrum. It might also be proved that those rays, powerful as they are, and sufficient to fuse many metals, can be permitted to enter the eye, and to break upon the retina, without producing the least luminous impression.

The dark rays being thus collected, you see nothing at their place of convergence. With a proper thermometer it could be proved that even the air at the focus is just as cold as the surrounding air. And mark the conclusion to which this leads. It proves the *aether* at the focus to be practically detached from the air,—that the most violent aethereal motion may there exist, without the least aërial motion. But, though you see it not, there is sufficient heat at that focus to set London on fire. The heat there is competent to raise iron to a temperature at which it throws off brilliant scintillations. It can heat platinum to whiteness, and almost fuse that refractory metal. It actually can fuse gold, silver, copper, and aluminium. The moment, moreover, that wood is placed at the focus it bursts into a blaze.

It has been already affirmed that, whether as regards radiation or absorption, the elementary atoms possess but little power. This might be illustrated by a long array of facts; and one of the most singular of these is furnished by the deportment of that extremely combustible substance, phosphorus, when placed at the dark focus. It is impossible to ignite there a fragment of amorphous phosphorus. But ordinary phosphorus is a far quicker combustible, and its deportment towards radiant heat is still more impressive. It may be exposed to the intense radiation of an ordinary fire without bursting into flame. It may also be exposed for twenty or thirty seconds at an obscure focus, of sufficient power to raise platinum to a red heat, without ignition. Notwithstanding the energy of the aethereal waves here concentrated, notwithstanding the extremely inflammable character of the elementary body exposed to their action, the atoms of that body refuse to partake of the motion of the powerful waves of low refrangibility, and consequently cannot be affected by their heat.

The knowledge we now possess will enable us to analyse with profit a practical question. White dresses are worn in summer, because they are found to be cooler than dark ones. The celebrated Benjamin Franklin placed bits of cloth of various colours upon snow, exposed them to direct sunshine, and found that they sank to different depths in the snow. The black cloth sank deepest, the white did not sink at all. Franklin inferred from this experiment that black bodies are the best absorbers, and white ones the worst absorbers, of radiant heat. Let us test the generality of this conclusion. One of these two cards is coated with a very dark powder, and the other with a perfectly white one. I place the powdered surfaces before a fire, and leave them there until they have acquired as high a temperature as they can attain in this position. Which of the cards is then most highly heated? It requires no thermometer to answer this question? Simply pressing the back of the card, on which the white powder is strewn, against the cheek or forehead, it is found intolerably hot. Placing the dark card in the same position, it is found cool. The white powder has absorbed far more heat than the dark one. This simple result abolishes a hundred conclusions which have been hastily drawn from the experiment of Franklin. Again, here are suspended two delicate mercurial thermometers at the same distance from a gas-flame. The bulb of one of them is covered by a dark substance, the bulb of the other by a white one. Both bulbs have received the radiation from the flame, but the white bulb has absorbed most, and its mercury stands much higher than that of the other thermometer. This experiment might be varied in a *hundred* ways: it proves that from the darkness of a body you can draw no certain conclusion regarding its power of absorption.

The reason of this simply is, that colour gives us intelligence of only one portion, and that the smallest one, of the rays impinging on the coloured body. Were the rays all luminous, we might with certainty infer from the colour of a body its power of absorption; but the great mass of the radiation from our fire, our gas-flame, and even from the sun itself, consists of invisible calorific rays, regarding which colour teaches us nothing. A body may be highly transparent to the one class of rays, and highly opaque to the other. Thus the white powder, which has shown itself so powerful an absorber, has been specially selected on account of its extreme perviousness to the visible rays, and its extreme imperviousness to the invisible ones; while the dark powder was chosen on account of its extreme transparency to the invisible, and its extreme opacity to the visible, rays. In the case of the radiation from our fire, about 98 per cent. of the whole emission consists of invisible rays; the body, therefore, which was most opaque to these triumphed as an absorber, though that body was a white one.

And here it is worth while to consider the manner in which we obtain from natural facts what may be called their intellectual value. Throughout the processes of Nature we have interdependence and harmony; and the main value of physics, considered as a mental discipline, consists in the tracing out of this interdependence, and the demonstration of this harmony. The outward and visible phenomena are the counters of the intellect; and our science would not be worthy of its name and fame if it halted at facts, however practically useful, and neglected the laws which accompany and rule the phenomena. Let us endeavour, then, to extract from the experiment of Franklin all that it can yield, calling to our aid the knowledge which our predecessors have already stored. Let us imagine two pieces of cloth of the same texture, the one black and the other white, placed upon sunned snow. Fixing our attention on the white piece, let us enquire whether there is any reason to expect that it will sink in the snow at all. There is knowledge at hand which enables us to reply at once in the negative. There is, on the contrary, reason to expect that, after a sufficient exposure, the bit of cloth will be found on an eminence instead of in a hollow; that instead of a depression, we shall have a *relative* elevation of the bit of cloth. For, as regards the luminous rays of the sun, the cloth and the snow are alike powerless; the one cannot be warmed, nor the other melted, by such rays. The cloth is white and the snow is white, because their confusedly mingled fibres and particles are incompetent to absorb the luminous rays. Whether, then, the cloth will sink or not depends entirely upon the dark rays of the sun. Now the substance which absorbs these dark rays with the greatest avidity is ice,—or snow, which is merely ice in powder. Hence, a less amount of heat will be lodged in the cloth than in the surrounding snow. The cloth must therefore act as a shield to the snow on which it rests; and, in consequence of the more rapid fusion of the exposed snow, its shield must, in due time, be left behind, perched upon an eminence like a glacier-table.

But though the snow transcends the cloth, both as a radiator and absorber, it does not *much* transcend it. Cloth is very powerful in both these respects. Let us now turn our attention to the piece of black cloth, the texture and fabric of which I assume to be the same as that of the white. For our object being to compare the effects of colour, we must, in order to study this effect in its purity, preserve all the other conditions constant. Let us then suppose the black cloth to be obtained from the dyeing of the white. The cloth itself, without reference to the dye, is nearly as good an absorber of heat as the snow around it. But to the absorption of the dark solar rays by the undyed cloth, is now added the absorption of the whole of the luminous rays, and this great additional influx of heat is far more than sufficient to turn the balance in favour of the black cloth. The sum of its actions on the dark and luminous rays, exceeds the action of the snow on the dark rays alone. Hence the cloth will sink in the snow, and this is the complete analysis of Franklin's experiment.

Throughout this discourse the main stress has been laid on chemical constitution, as influencing most powerfully the phenomena of radiation and absorption. With regard to gases and vapours, and to the liquids from which these vapours are derived, it has been proved by the most varied and conclusive experiments that the acts of radiation and absorption are *molecular*—that they depend upon chemical, and not upon mechanical, condition. In attempting to extend this principle to solids I was met by a multitude of facts, obtained by celebrated experimenters, which seemed flatly to forbid such an extension. Melloni, for example, had found the same radiant and absorbent power for chalk and lamp-black. MM. Masson and Courtépée had performed a most elaborate series of experiments on chemical precipitates of various kinds, and found that they one and all manifested the same power of radiation. They concluded from their researches, that when bodies are reduced to an extremely fine state of division, the influence of this state is so powerful as entirely to mask and override whatever influence may be due to chemical constitution.

But it appears to me that through the whole of these researches an oversight has run, the mere mention of which will show what caution is essential in the operations of experimental philosophy; while an experiment or two will make clear wherein the oversight consists. Filling a brightly polished metal cube with boiling water, I determine the quantity of heat emitted by two of the bright surfaces. As a radiator of heat one of them far transcends the other. Both surfaces appear to be metallic; what, then, is the cause of the observed difference in their radiative power? Simply this: one of the surfaces is coated with transparent gum, through which, of course, is seen the metallic lustre behind; and this varnish, though so perfectly transparent to luminous rays, is as opaque as pitch, or lamp-black, to non-luminous ones. It is a powerful emitter of dark rays; it is also a powerful absorber. While, therefore, at the present moment, it is copiously pouring forth radiant heat itself, it does not allow a single ray from the metal behind to pass through it. The varnish then, and not the metal, is the real radiator.

Now Melloni, and Masson, and Courtépée experimented thus: they mixed their powders and precipitates with gum-water, and laid them, by means of a brush, upon the surfaces of a cube like this. True, they saw their red powders red, their white ones white, and their black ones black, but they saw these colours *through the coat of varnish which encircled every particle of their powders.* When, therefore, it was concluded that colour had no influence on radiation, no chance had been given to it of asserting its influence; when it was found that all chemical precipitates radiated alike, it was the radiation from a varnish, common to them all, which showed the observed constancy. Hundreds, perhaps thousands, of experiments on radiant heat have been performed in this way, by various enquirers, but the work will, I fear, have to be done over again. I am not, indeed, acquainted with an instance in which an oversight of so trivial a character has been committed by so many able men in succession, and vitiated so large an amount of otherwise excellent work.

Basing our reasonings thus on demonstrated facts, we arrive at the extremely probable conclusion that the envelope of the particles, and not the particles themselves, was the real radiator in the experiments just referred to. To reason thus, and deduce their more or less probable consequences from experimental facts, is an incessant exercise of the student of physical science. But having thus followed, for a time, the light of reason alone through a series of phenomena, and emerged from them with a purely intellectual conclusion, our duty is to bring that conclusion to an experimental test. In this way we fortify our science, sparing no pains and shirking no toil, to secure sound materials for the edifice which it is our privilege to raise.

For the purpose of testing our conclusion regarding the influence of the gum, I take two powders presenting the same physical appearance; one of them is a compound of mercury, and the other a compound of lead. On two surfaces of a cube are spread these bright red powders, without varnish of any kind. Filling the cube with boiling water, and determining the radiation from the two surfaces, one of them is found to emit thirty-nine units of heat, while the other emits seventy-four. This, surely, is a great difference. Here, however, is a second cube, having two of its surfaces coated with the same powders, the only difference being that the powders are laid on by means of a transparent gum. Both surfaces are now absolutely alike in radiative power. Both of them emit somewhat more than was emitted by either of the unvarnished powders, simply because the gum employed is a better radiator than either of them. Excluding all varnish, and comparing white with white, vast differences are found; comparing black with black, they are also different; and when black and white are compared, in some cases the black radiates far more than the white, while in other cases the white radiates far more than the black. Determining, moreover, the absorptive power of those powders, it is found to go hand-in-hand with their radiative power. The good radiator is a good absorber, and the bad radiator is a bad absorber. From all this it is evident that as regards the radiation and absorption of non-luminous heat, colour teaches us nothing; and that even as regards the radiation of the sun, consisting as it does mainly of non-luminous rays, conclusions as to the influence of colour may be altogether delusive. This is the strict scientific upshot of our researches. But it is not the less true that in the case of wearing apparel—and this for reasons which I have given in analysing the experiment of Franklin—black dresses are more potent than white ones as absorbers of solar heat.

Thus, in brief outline, have been brought before you a few of the results of recent enquiry. If you ask me what is the use of them, I can hardly answer you, unless you define the term use. If you meant to ask whether those dark rays which clear away the Alpine snows, will ever be applied to the roasting of turkeys, or the driving of steam-engines—while affirming their power to do both, I would frankly confess that they are not at present capable of competing profitably with coal in these particulars. Still they may have great uses unknown to me; and when our coal-fields are exhausted, it is possible that a more aethereal race than we are may cook their victuals, and perform their work, in this transcendental way. But is it necessary that the student of science *should have his* labours tested by their possible practical applications? What is the practical value of Homer's Iliad? You smile, and possibly think that Homer's Iliad is good as a means of culture. There's the rub. The people who demand of science practical uses, forget, or do not know, that it also is great as a means of culture—that the knowledge of this wonderful universe is a thing profitable in itself, and requiring no practical application to justify its pursuit.

But while the student of Nature distinctly refuses to have his labours judged by their practical issues, unless the term practical be made to include mental as well as material good, he knows full well that the greatest practical triumphs have been episodes in the search after pure natural truth. The electric telegraph is the standing wonder of this age, and the men whose scientific knowledge, and mechanical skill, have made the telegraph what it is, are deserving of all honour. In fact, they have had their reward, both in reputation and in those more substantial benefits which the direct service of the public always carries in its train. But who, I would ask, put the soul into this telegraphic body? Who snatched from heaven the fire that flashes along the line? This, I am bound to say, was done by two men, the one a dweller in Italy,[1] the other a dweller in England,[2] who never in their enquiries consciously set a practical object before them,—whose only stimulus was the fascination which draws the climber to a never-trodden peak, and would have made Cæsar quit his victories for the sources of the Nile. That the knowledge brought us by those prophets, priests, and kings of science is what the world calls useful knowledge, the triumphant application of their discoveries proves. But science has another function to fulfil, in the storing and the training of the human mind; and I would base my appeal to you on the specimen which has this evening been brought before you, whether any system of education at the present day can be deemed even approximately complete, in which the knowledge of Nature is neglected or ignored.

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[1] Volta. [2] Faraday.

The opening paragraph of this article, as indeed many others in this volume, show that 'the crossing of the boundary of experiment,' the mention of which caused so much commotion last year, is no new heresy of mine. December 1875.

IV.

NEW CHEMICAL REACTIONS PRODUCED BY LIGHT.

1868–69.

§ 1.

IN 1868 I asked permission of the Royal Society to draw the attention of chemists to a method of experiment which, though simple, was unknown. It consists in subjecting the vapours of volatile liquids to the action of concentrated sunlight, or to the concentrated beam of the electric light. This communication was the immediate antecedent of the discourse on 'Dust and Disease' which follows it in this volume; and as such is introduced here.

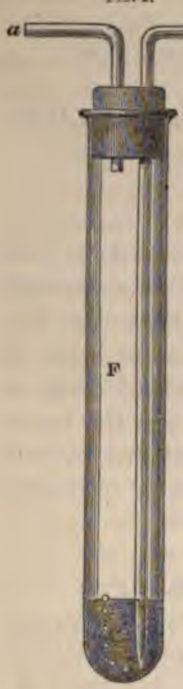
Action of the Electric Light.

A glass tube 2·8 feet long and of 2·5 inches internal diameter, which had been frequently employed in my researches on radiant heat, was supported horizontally. At one end of it was placed an electric lamp, the height and position of both being so arranged, that the axis of the glass tube, and that of the parallel beam issuing from the lamp, were coincident. The tube in the first experiments was closed by plates of rock-salt, and subsequently by plates of glass.

This tube which, as on former occasions, for the sake of distinction, I call *the experimental tube*, was connected with an air-pump, and also with a series of drying and other tubes used for the purification of the air.

A number of test-tubes, like F, fig. 2 (I have used at least fifty of them), were converted into Woulf's flasks. Each of them was stopped by a cork, through which passed two glass tubes: one of these tubes (a) ended immediately below the cork, while the other (b) descended to the bottom of the flask, being drawn out at its lower end to an orifice about 0·03 of an inch in diameter. It was found necessary to coat the cork carefully with cement.

Fig. 2.



The little flask, thus formed, was partially filled with the liquid whose vapour was to be examined; it was then introduced into the path of the purified current of air.

The experimental tube being exhausted, and the cock which cut off the supply of purified air being cautiously turned on, the air entered the flask through the tube b, and escaped by the small orifice at the lower end of b into the liquid. Through this it bubbled, loading itself with vapour, after which the mixed air and vapour, passing from the flask by the tube a, entered the experimental tube, where they were subjected to the action of light.

The power of the electric beam to reveal the existence of anything within the experimental tube, or the impurities of the tube itself, is extraordinary. When the experiment is made in a darkened room, a tube which in ordinary daylight appears absolutely clean, is often shown by the present mode of examination to be exceedingly filthy.

The following are some of the results obtained with this arrangement:—

Nitrite of amyl.—The vapour of this liquid was in the first instance permitted to enter the experimental tube, while the beam from the electric lamp was passing through it. Curious clouds were observed to form near the place of entry, which were afterwards whirled through the tube.

The tube being again exhausted, the mixed air and vapour were allowed to enter it in the dark. The slightly convergent beam of the electric light was then sent through the tube, from end to end. For a moment the tube was *optically empty*, nothing whatever was seen within it; but before a second had elapsed a shower of liquid spherules was precipitated on the beam, thus generating a cloud within the tube. This cloud became denser as the light continued to act, showing at some places vivid iridescence.

The beam of the electric lamp was now converged so as to form within the tube a cone of rays about eight inches long. The tube was cleansed and again filled in darkness. When the light was sent through it, the precipitation upon the beam was so rapid and intense that the cone, which a moment before was invisible, flashed suddenly forth like a solid luminous spear.

The effect was the same when the air and vapour were allowed to enter the tube in diffuse daylight. The cloud, however, which shone with such extraordinary radiance under the electric beam, was invisible in the ordinary light of the laboratory.

The quantity of mixed air and vapour within the experimental tube could of course be regulated at pleasure. The rapidity of the action diminished with the attenuation of the vapour. When, for example, the mercurial column associated with the experimental tube was depressed only five inches, the action was not nearly so rapid as when the tube was full. In such cases, however, it was exceedingly interesting to observe, after some seconds of waiting, a thin streamer of delicate bluish-white cloud slowly forming along the axis of the tube, and finally swelling so as to fill it.

When dry oxygen was employed to carry in the vapour, the effect was the same as that obtained with air.

When dry hydrogen was used as a vehicle, the effect was also the same.

The effect, therefore, is not due to any interaction between the vapour of the nitrite and its vehicle.

This was further demonstrated by the deportment of the vapour itself. When it was permitted to enter the experimental tube unmixed with air or any other gas, the effect was substantially the same. Hence the seat of the observed action is the vapour.

This action is not to be ascribed to heat. With reference to the glass of the experimental tube, and the air within the tube, the beam employed in these experiments was perfectly cold. It had been sifted by passing it through a solution of alum, and through the thick double-convex lens of the lamp. When the unsifted beam of the lamp was employed, the effect was still the same; the obscure calorific rays did not appear to interfere with the result.

My object here being simply to point out to chemists a method of experiment which reveals a new and beautiful series of reactions, to them I leave the examination of the products of decomposition. The molecule of the nitrite of amyl is obviously shaken asunder by certain specific waves of the electric beam, forming, doubtless, nitric oxide and other products, of which the *nitrate* of amyl is probably one. The brown fumes of nitrous acid were also seen to mingle with the cloud within the experimental tube. *The nitrate* of amyl, being less volatile than the nitrite, and not being able to maintain itself in the condition of vapour, would be precipitated as a visible cloud along the track of the beam.

In the anterior portions of the tube a sifting of the beam by the vapour occurs, which diminishes the chemical action in the posterior portions. In some experiments the precipitated cloud only extended halfway down the tube. When, under these circumstances, the lamp was shifted so as to send the beam through the other end of the tube, precipitation occurred there also.

Action of Sunlight.

Solar light also effects the decomposition of the nitrite-of-amyl vapour. On October 10 I partially darkened a small room in the Royal Institution, into which the sun shone, permitting the light to enter through an open portion of the window-shutter. In the track of the beam was placed a large plano-convex lens, which formed a fine convergent cone in the dust of the room behind it. The experimental tube was filled in the laboratory, covered with a black cloth, and carried into the partially darkened room. On thrusting one end of the tube into the cone of rays behind the lens, precipitation within the cone was copious and immediate. The vapour at the distant end of the tube was in part shielded by that in front, and was also more feebly acted on through the divergence of the rays. On reversing the tube, a second and similar cone was precipitated.

Physical Considerations.

I sought to determine the particular portion of the white beam which produced the foregoing effects. When, previous to entering the experimental tube, the beam was caused to pass through a red glass, the effect was greatly weakened, but not extinguished. This was also the case with various samples of yellow glass. A blue glass being introduced, before the removal of the yellow or the red, on taking the latter away augmented precipitation occurred along the track of the blue beam. Hence, in this case, the more refrangible rays are the most chemically active.

The colour of the liquid nitrite of amyl indicates that this must be the case; it is a feeble but distinct yellow: in other words, the yellow portion of the beam is most freely transmitted. It is not, however, the transmitted portion of any beam which produces chemical action, but the absorbed portion. Blue, as the complementary colour to yellow, is here absorbed, and hence the more energetic action of the blue rays. This reasoning, however, assumes that the same rays are absorbed by the liquid and its vapour.

A solution of the yellow chromate of potash, the colour of which may be made almost, if not altogether, identical with that of the liquid nitrite of amyl, was found far more effective in stopping the chemical rays than either the red or the yellow glass. But of all substances the nitrite itself is most potent in arresting the rays which act upon its vapour. A layer one-eighth of an inch in thickness, which scarcely preceptibly affected the luminous intensity, sufficed to absorb the entire chemical energy of the concentrated beam of the electric light.

The close relation subsisting between a liquid and its vapour, as regards their action upon radiant heat, has been already amply demonstrated.[1] As regards the nitrite of amyl, this relation is more specific than in the cases hitherto adduced; for here the special constituent of the beam, which provokes the decomposition of the vapour, is shown to be arrested by the liquid.

A question of extreme importance in molecular physics here arises: What is the real mechanism of this absorption, and where is its seat?[1]

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[1] 'Phil. Trans.' 1864; and p. 59 of this volume.

I figure, as others do, a molecule as a group of atoms, held together by their mutual forces, but still capable of motion among themselves. The vapour of the nitrite of amyl is to be regarded as an assemblage of such molecules. The question now before us is this: In the act of absorption, is it the molecules that are effective, or is it their constituent atoms? Is the *vis viva* of the intercepted light-waves transferred to the molecule as a whole, or to its constituent parts?

The molecule, as a whole, can only vibrate in virtue of the forces exerted between it and its neighbour molecules. The intensity of these forces, and consequently the rate of vibration, would, in this case, be a function of the distance between the molecules. Now the identical absorption of the liquid and of the vaporous nitrite of amyl indicates an identical vibrating period on the part of liquid and vapour, and this, to my mind, amounts to an experimental demonstration that the absorption occurs in the main *within* the molecule For it can hardly be supposed, if the absorption were the act of the molecule as a whole, that it could continue to affect waves of the same period after the substance had passed from the vaporous to the liquid state.

In point of fact, the decomposition of the nitrite of amyl is itself to some extent an illustration of this internal molecular absorption; for were the absorption the act of the molecule as a whole, the *relative* motions of its constituent atoms would remain unchanged, and there would be no mechanical cause for their separation. It is probably the synchronism of the vibrations of one portion of the molecule with the incident waves, that enables the

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[1] My attention was very forcibly directed to this subject some years ago by a conversation with my excellent friend Professor Clausius.

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amplitude of those vibrations to augment, until the chain which binds the parts of the molecule together is snapped asunder.

The *liquid* nitrite of amyl is probably also decomposed by light; but the reaction, if it exists, is incomparably less rapid and distinct than that of the vapour. Nitrite of amyl has been subjected to the concentrated solar rays until it boiled, and it has been permitted to continue boiling for a considerable time, without any distinctly apparent change occurring in the liquid.

I anticipate wide, if not entire, generality for the fact that a liquid and its vapour absorb the same rays. A cell of liquid chlorine now preparing for me will, I imagine, deprive light more effectually of its power of causing chlorine and hydrogen to combine than any other filter of the luminous rays. The rays which give chlorine its colour have nothing to do with this combination, those that are absorbed by the chlorine being the really effective rays. A highly sensitive bulb, containing chlorine and hydrogen, in the exact proportions necessary for the formation of hydrochloric acid, was placed at one end of an experimental tube, the beam of the electric lamp being sent through it from the other. The bulb did not explode when the tube was filled with chlorine, while the explosion was violent and immediate when the tube was filled with air. I anticipate for the liquid chlorine an action similar to, but still more energetic than, that exhibited by the gas. If this should prove to be the case, it will favour the view that chlorine itself is *molecular* and not *monatomic*.

Production of Sky-blue by the Decomposition of Nitrite of Amyl.

When the quantity of nitrite vapour is considerable, and the light intense, the chemical action is exceedingly rapid, the particles precipitated being so large as to *whiten* the luminous beam. Not so, however, when a well-mixed and highly attenuated vapour fills the experimental tube. The effect now to be described was first obtained when the vapour of the nitrite was derived from a portion of its liquid, accidentally introduced into the passage through which the dry air flowed into the experimental tube.

In this case, the electric beam traversed the tube for several seconds before any action was visible. Decomposition then visibly commenced, and advanced slowly. When the light was very strong, the cloud appeared of a milky blue. When, on the contrary, the intensity was moderate, the blue was pure and deep. In Brücke's important experiments on the blue of the sky and the morning and evening red, pure mastic is dissolved in alcohol, and then dropped into water well stirred. When the proportion of mastic to alcohol is correct, the resin is precipitated so finely as to elude the highest microscopic power. By reflected light, such a medium appears bluish, by transmitted light yellowish, which latter colour, by augmenting the quantity of the precipitate, can be caused to pass into orange or red.

But the development of colour in the attenuated nitrite-of-amyl vapour, though admitting of the same explanation, is doubtless more similar to what takes place in our atmosphere. The blue, moreover, is far purer and more sky-like than that obtained from Brücke's turbid medium. Never, even in the skies of the Alps, have I seen a richer or a purer blue than that attainable by a suitable disposition of the light falling upon the precipitated vapour.

In exhausting the tube containing the mixed air and nitrite-of-amyl vapour, it was difficult to avoid explosions under the pistons of the air-pump, similar to those which

I have already described as occurring with the vapours of bisulphide of carbon and other substances. Though the quantity of vapour present in these cases must have been infinitesimal, its explosion was sometimes sufficient to destroy the valves of the pump.

Iodide of Allyl.—Among the liquids hitherto subjected to the concentrated electric light, iodide of allyl, in point of rapidity and intensity of action, comes next to the nitrite of amyl. With the iodide of allyl I have employed both oxygen and hydrogen, as well as air, as a vehicle, and found the effect in all cases substantially the same. The cloud-column here was exquisitely beautiful. It revolved round the axis of the decomposing beam; it was nipped at certain places like an hour-glass, and round the two bells of the glass delicate cloud-filaments twisted themselves in spirals. It also folded itself into convolutions resembling those of shells. In certain conditions of the atmosphere in the Alps I have often observed clouds of a special pearly lustre; when hydrogen was made the vehicle of the iodide-of-allyl vapour a similar lustre was most exquisitely shown. With a suitable disposition of the light, the purple hue of iodine-vapour came out very strongly in the tube.

The remark already made, as to the bearing of the decomposition of nitrite of amyl by light on the question of molecular absorption, applies here also; for were the absorption the work of the molecule as a whole, the iodine would not be dislodged from the allyl with which it is combined. The non-synchronism of iodine with the waves of obscure heat is illustrated by its marvellous transparency to such heat. May not its synchronism with the waves of light in the present instance be the cause of its divorce from the allyl? Further experiments on this point are in preparation.

Iodide of Isopropyl.—The action of light upon the vapour of this liquid is, at first, more languid than upon iodide of allyl; indeed many beautiful reactions may be overlooked, in consequence of this languor at the commencement. After some minutes' exposure, however, clouds begin to form, which grow in density and in beauty as the light continues to act. In every experiment hitherto made with this substance the column of cloud filling the experimental tube, was divided into two distinct parts near the middle of the tube. In one experiment a globe of cloud formed at the centre, from which, right and left, issued an axis uniting the globe with two adjacent cylinders. Both globe and cylinders were animated by a common motion of rotation. As the action continued, paroxysms of motion were manifested; the various parts of the cloud would rush through each other with sudden violence. During these motions beautiful and grotesque cloud-forms were developed. At some places the nebulous mass would become ribbed so as to resemble the graining of wood; a longitudinal motion would at times generate in it a series of curved transverse bands, the retarding influence of the sides of the tube causing an appearance resembling, on a small scale, the dirt-bands of the Mer de Glace. In the anterior portion of the tube those sudden commotions were most intense; here buds of cloud would sprout forth, and grow in a few seconds into perfect flower-like forms. The cloud of iodide of isopropyl had a character of its own, and differed materially from all others that I had seen. A gorgeous mauve colour was observed in the last twelve inches of the tube; the vapour of iodine was present, and it may have been the sky-blue scattered by the precipitated particles which, mingling with the purple of the iodine, produced the mauve. As in all other cases here adduced, the effects were proved to be due to the light; they never occurred in darkness.

The forms assumed by some of those actinic clouds, in consequence of rotations and other motions, due to differences of temperature, are perfectly astounding. I content myself here with a meagre description of one more of them.

The tube being filled with the sensitive mixture, the beam was sent through it, the lens at the same time being so placed as to produce a cone of very intense light. Two minutes elapsed before anything was visible; but at the end of this time a faint bluish cloud appeared to hang itself on the most concentrated portion of the beam.

Soon afterwards a second cloud was formed five inches farther down the experimental tube. Both clouds were united by a slender cord of the same bluish tint as themselves.

As the action of the light continued, the first cloud gradually resolved itself into a series of parallel disks of exquisite delicacy, which rotated round an axis perpendicular to their surfaces, and finally blended to a screw surface with an inclined generatrix. This gradually changed into a filmy funnel, from the narrow end of which the 'cord' extended to the cloud in advance. The latter also underwent slow but incessant modification. It first resolved itself into a series of strata resembling those of the electric discharge. After a little time, and through changes which it was difficult to follow, both clouds presented the appearance of a series of concentric funnels set one within the other, the interior ones being seen through the outer ones. Those of the distant cloud resembled claret-glasses in shape. As many as six funnels were th [illegible] concentrically set together, the two series bei [illegible] by the delicate cord of cloud already re- [illegible] er cords and slender tubes were afterwards [illegible] coiled themselves in delicate spirals around [illegible]

[illegible] g the light along the connecting-cord more intense, it diminished in thickness and became whiter; this was a consequence of the enlargement of its particles. The cord finally disappeared, while the funnels melted into two ghost-like films, shaped like parasols. They were barely visible, being of an exceedingly delicate blue tint. They seemed woven of blue air. To compare them with cobweb or with gauze would be to liken them to something infinitely grosser than themselves.

In all cases a distant candle-flame, when looked at through the cloud, was sensibly undimmed.

§ 2. On the Blue Colour of the Sky, and the Polarisation of Skylight.[1]

1869.

After the communication of the foregoing brief abstract 'On a new Series of Chemical Reactions produced by Light,' the experiments upon this subject were continued, the number of substances thus acted on being considerably increased.

I now beg to direct attention to two questions glanced at incidentally in the abstract referred to—the blue colour of the sky, and the polarisation of skylight. Reserving the historic treatment of the subject for a more fitting occasion, I would merely mention now that these questions constitute, in the opinion of our most eminent authorities, the two great standing enigmas of meteorology. Indeed it was the interest manifested in them by Sir John Herschel, in a letter of singular speculative power, addressed to myself, that caused me to enter upon the consideration of these questions so soon.

The apparatus with which I work consists, as already stated, of a glass tube about a yard in length, and from

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[1] In my 'Lectures on Light' (Longmans), the polarisation of light will be *found briefly, but, I trust, clearly* explained.

2½ to 3 inches internal diameter. The vapour to be examined is introduced into this tube in the manner described in my last abstract, and upon it the condensed beam of the electric lamp is permitted to act, until the neutrality or the activity of the substance has been declared.

It has hitherto been my aim to render the chemical action of light upon vapours *visible*. For this purpose substances have been chosen, one at least of whose products of decomposition under light shall have a boiling-point so high, that as soon as the substance is formed it shall be *precipitated*. By graduating the quantity of the vapour, this precipitation may be rendered of any degree of fineness, forming particles distinguishable by the naked eye, or far beyond the reach of our highest microscopic powers.

I have no reason to doubt that particles may be thus obtained, whose diameters constitute but a small fraction of the length of a wave of violet light.

In all cases when the vapours of the liquids employed are sufficiently attenuated, no matter what the liquid may be, the visible action commences with the formation of a *blue cloud*. I would guard myself at the outset against all misconception as to the use of this term. The 'cloud' here referred to is totally invisible in ordinary daylight. To be seen, it requires to be surrounded by darkness, *it only* being illuminated by a powerful beam of light. This blue cloud differs in many important particulars from the finest ordinary clouds, and might justly have assigned to it an intermediate position between such clouds and true vapour.

With this explanation, the term 'cloud,' or 'incipient cloud,' as I propose to employ it, cannot, I think, be misunderstood.

I had been endeavouring to decompose carbonic acid gas by light. A faint bluish cloud, due it may be, or it may not be, to the residue of some vapour previously employed, was formed in the experimental tube. On looking across this cloud through a Nicol's prism, the line of vision being horizontal, it was found that when the short diagonal of the prism was vertical, the quantity of light reaching the eye was greater than when the long diagonal was vertical.

When a plate of tourmaline was held between the eye and the bluish cloud, the quantity of light reaching the eye when the axis of the prism was perpendicular to the axis of the illuminating beam, was greater than when the axes of the crystal and of the beam were parallel to each other.

This was the result all round the experimental tube. Causing the crystal of tourmaline to revolve round the tube, with its axis perdendicular to the illuminating beam, the quantity of light that reached the eye was in all its positions a maximum. When the crystallographic axis was parallel to the axis of the beam, the quantity of light transmitted by the crystal was a minimum.

From the illuminated bluish cloud, therefore, polarised light was discharged, the direction of maximum polarisation being at right angles to the illuminating beam; the plane of vibration of the polarised light was perpendicular to the beam.[1]

Thin plates of selenite or of quartz, placed between the Nicol and the bluish cloud, displayed the colours of polarised light, these colours being most vivid when the line of vision was at right angles to the experimental tube. The plate of selenite usually employed was a circle, thinnest at the centre, and augmenting uniformly in thickness from the centre outwards. When placed in its proper position between the Nicol and the cloud, it exhibited a system of splendidly-coloured rings.

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[1] This is still an undecided point; but the probabilities are so much in its favour, and it is in my opinion so much preferable to have a physical image on which the mind can rest, that I do not hesitate to employ the phraseology in the text.

The cloud here referred to was the first operated upon in the manner described. It may, however, be greatly improved upon by the choice of proper substances, and by the application, in proper quantities, of the substances chosen. Benzol, bisulphide of carbon, nitrite of amyl, nitrite of butyl, iodide of allyl, iodide of isopropyl, and many other substances may be employed. I will take the nitrite of butyl as illustrative of the means adopted to secure the best result, with reference to the present question.

And here it may be mentioned that a vapour, which when alone, or mixed with air in the experimental tube, resists the action of light, or shows but a feeble result of this action, may, when placed in proximity with another gas or vapour, exhibit vigorous, if not violent action. The case is similar to that of carbonic acid gas, which, diffused in the atmosphere, resists the decomposing action of solar light, but when placed in contiguity with chlorophyl in the leaves of plants, has its molecules shaken asunder.

Dry air was permitted to bubble through the liquid nitrite of butyl, until the experimental tube, which had been previously exhausted, was filled with the mixed air and vapour. The visible action of light upon the mixture after fifteen minutes' exposure was slight. The tube was afterwards filled with half an atmosphere of the mixed air and vapour, and a second half-atmosphere of air which had been permitted to bubble through fresh commercial hydrochloric acid. On sending the beam through this mixture, the tube, for a moment, was optically empty. But the pause amounted only to a small fraction of a second, a dense cloud being immediately precipitated upon the beam.

This cloud began *blue*, but the advance to whiteness was so rapid as almost to justify the application of the term instantaneous. The dense cloud, looked at perpendicularly to its axis, showed scarcely any signs of polarisation. Looked at obliquely the polarisation was strong.

The experimental tube being again cleansed and exhausted, the mixed air and nitrite-of-butyl vapour was permitted to enter it until the associated mercury column was depressed $\frac{1}{10}$ of an inch. In other words, the air and vapour, united, exercised a pressure not exceeding $\frac{1}{300}$ of an atmosphere. Air, passed through a solution of hydrochloric acid, was then added, till the mercury column was depressed three inches. The condensed beam of the electric light passed for some time in darkness through this mixture. There was absolutely nothing within the tube competent to scatter the light. Soon, however, a superbly blue cloud was formed along the track of the beam, and it continued blue sufficiently long to permit of its thorough examination. The light discharged from the cloud, at right angles to its own length, was *perfectly* polarised. By degrees the cloud became of whitish blue, and for a time the selenite colours, obtained by looking at it normally were exceedingly brilliant. The direction of maximum polarisation was distinctly at right angles to the illuminating beam. This continued to be the case as long as the cloud maintained a decided blue colour, and even for some time after the pure blue had changed to whitish blue. But, as the light continued to act, the cloud became coarser and whiter, particularly at its centre, where it at length ceased to discharge polarised light in the direction of the perpendicular, while it continued to do so at both its ends.

But the cloud which had thus ceased to polarise the light emitted normally, showed vivid selenite colours when looked at *obliquely*, proving that the direction of maximum polarisation changed with the texture of the cloud. This point shall receive further illustration subsequently.

A blue, equally rich and more durable, was obtained by employing the nitrite-of-butyl vapour in a still more attenuated condition. Now the instance here cited is *representative*. In all cases, and with all substances, the cloud formed at the commencement, when the precipitated particles are sufficiently fine, is *blue*, and it can be made to display a colour rivalling that of the purest Italian sky. In all cases, moreover, this fine blue cloud polarises *perfectly* the beam which illuminates it, the direction of polarisation enclosing an angle of 90° with the axis of the illuminating beam.

It is exceedingly interesting to observe both the perfection and the decay of this polarisation. For ten or fifteen minutes after its first appearance the light from a vividly illuminated incipient cloud, looked at perpendicularly, is absolutely quenched by a Nicol's prism with its longer diagonal vertical. But as the sky-blue is gradually rendered impure by the introduction of particles of too large a size—in other words, as real clouds begin to be formed—the polarisation begins to deteriorate, a portion of the light passing through the prism in all its positions. It is worthy of note, that for some time after the cessation of perfect polarisation, the *residual* light which passes, when the Nicol is in its position of minimum transmission, is of a gorgeous blue, the whiter light of the cloud being extinguished.[1] When the cloud texture has become sufficiently coarse to approximate to that of ordinary clouds, the rotation of the Nicol ceases to have any sensible effect on the quantity of light discharged normally.

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[1] This shows that particles too large to polarise the blue, polarise perfectly light of lower refrangibility.

The perfection of the polarisation, in a direction perpendicular to the illuminating beam, is also illustrated by the following experiment: A Nicol's prism, large enough to embrace the entire beam of the electric lamp, was placed between the lamp and the experimental tube. A few bubbles of air, carried through the liquid nitrite of butyl, were introduced into the tube, and they were followed by about three inches (measured by the mercurial gauge) of air which had passed through aqueous hydrochloric acid. Sending the polarised beam through the tube, I placed myself in front of it, my eye being on a level with its axis, my assistant Mr. Cottrell occupying a similar position behind the tube. The short diagonal of the large Nicol was in the first instance vertical, the plane of vibration of the emergent beam being therefore also vertical. As the light continued to act, a superb blue cloud, visible to both my assistant and myself, was slowly formed. But this cloud, so deep and rich when looked at from the positions mentioned, *utterly disappeared when looked at vertically downwards, or vertically upwards.* Reflection from the cloud was not possible in these directions. When the large Nicol was slowly turned round its axis, the eye of the observer being on the level of the beam, and the line of vision perpendicular to it, entire extinction of the light emitted horizontally occurred when the longer diagonal of the large Nicol was vertical. But now a vivid blue cloud was seen when looked at downwards or upwards. This truly fine experiment was first definitely suggested by a remark in a letter addressed so me by Professor Stokes.

As regards the polarisation of skylight, the greatest stumbling-block has hitherto been, that, in accordance with the law of Brewster, which makes the index of refraction the tangent of the polarising angle, the reflection which produces perfect polarisation would require to be made *in* air *upon* air; and indeed this led many of our most eminent men, Brewster himself among the number, to entertain the idea of aërial molecular reflection.[1] I have, however, operated upon substances of widely different refractive indices, and therefore of very different polarising angles as ordinarily defined, but the polarisation of the beam, by the incipient cloud, has thus far proved itself to be *absolutely independent of the polarising angle.* The law of Brewster does not apply to matter in this condition, and it rests with the undulatory theory to explain why. Whenever the precipitated particles are sufficiently fine, no matter what the substance forming the particles may be, the direction of maximum polarisation is at right angles to the illuminating beam, the polarising angle for matter in this condition being invariably 45°.

Suppose our atmosphere surrounded by an envelope impervious to light. But with an aperture on the sunward side, through which a parallel beam of solar light could enter and traverse the atmosphere. Surrounded by air not directly illuminated, the track of such a beam through the air would resemble that of the parallel beam of the electric lamp through an incipient cloud. The sunbeam would be *blue*, and it would discharge laterally light in precisely the same condition as that discharged by the incipient cloud. In fact, the azure revealed by such a beam would be to all intents and purposes that which I have called a 'blue cloud.' Conversely our 'blue cloud' is, to all intents and purposes, an *artificial sky*.[1]

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[1] 'The cause of the polarisation is evidently a reflection of the sun's light upon *something.* The question is on what? Were the angle of maximum polarisation 76°, we should look to water or ice as the reflecting body, however inconceivable the existence in a cloudless atmosphere, and a hot summer's day of unevaporated molecules (particles?), of water. But though we were once of this opinion, careful observation has satisfied us that 90°, or thereabouts, is the correct angle, and that therefore whatever be the body on which the light has been reflected, *if polarised by a single reflection,* the polarising angle must be 45°, and the index of refraction, which is the tangent of that angle, unity; in other words, the reflection would require to be made *in* air *upon* air!' (Sir John Herschel, 'Meteorology,' par. 233.)

Any particles, if small enough, will produce both the colour and the polarisation of the sky. But is the existence of small water-particles on a hot summer's day *in the higher regions of our atmosphere* inconceivable? It is to be remembered that the oxygen and nitrogen of the air behave as a vacuum to radiant heat, the exceedingly attenuated vapour of the higher *atmosphere* being therefore in practical contact with the cold of space.

But, as regards the polarisation of the sky, we know that not only is the direction of maximum polarisation at right angles to the track of the solar beams, but that at certain angular distances, probably variable ones, from the sun, 'neutral points,' or points of no polarisation, exist, on both sides of which the planes of atmospheric polarisation are at right angles to each other.

I have made various observations upon this subject which are reserved for the present; but, pending the more complete examination of the question, the following facts bearing upon it may be submitted.

The parallel beam employed in these experiments tracked its way through the laboratory air, exactly as sunbeams are seen to do in the dusty air of London. I have reason to believe that a great portion of the matter thus floating in the laboratory air consists of organic particles, which are capable of imparting a perceptibly bluish tint to the air. These also showed, though far less vividly, all the effects of polarisation obtained with the incipient clouds. The light discharged laterally from the track of the illuminating beam was polarised, though not perfectly, the direction of maximum polarisation being at right angles to the beam.

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[1] The opinion of Sir John Herschel, connecting the polarisation and the blue colour of the sky is verified by the foregoing results. 'The more the subject [the polarisation of skylight] is considered,' writes this eminent philosopher, 'the more it will be found beset with difficulties, and its explanation when arrived at will probably be found to carry with it that of the blue colour of the sky itself, and of the great quantity of light it actually does send down to us.' 'We may observe, too,' he adds, 'that it is only where the purity of the sky is most absolute that the polarisation is developed in its highest degree, and that where there is the slightest perceptible tendency to cirrus it is materially impaired.' This applies word for word to our 'incipient clouds.'

The horizontal column of air, thus illuminated, was 18 feet long, and could therefore be looked at very obliquely. At all points of the beam, throughout its entire length, the light emitted normally was in the same state of polarisation. Keeping the positions of the Nicol and the selenite constant, the same colours were observed throughout the entire beam, when the line of vision was perpendicular to its length.

I then placed myself near the end of the beam, as it issued from the electric lamp, and, looking through the Nicol and selenite more and more obliquely at the beam, observed the colours fading until they disappeared. Augmenting the obliquity the colours appeared once more, *but they were now complementary to the former ones.*

Hence this beam, like the sky, exhibited a neutral point, on opposite sides of which the light was polarised in planes at right angles to each other.

Thinking that the action observed in the laboratory might be caused, in some way, by the vaporous fumes diffused in its air, I had the light removed to a room at the top of the Royal Institution. The track of the beam was seen very finely in the air of this room, a length of 14 or 15 feet being attainable. This beam exhibited all the effects observed with the beam in the laboratory. Even the uncondensed electric light falling on the floating matter showed, though faintly, the effects of polarisation.

When the air was so sifted as to entirely remove the *visible floating* matter, it no longer exerted any sensible action upon the light, but behaved like a vacuum. The light is scattered by *particles*, not by molecules or atoms.

By operating upon the fumes of chloride of ammonium, the smoke of brown paper, and tobacco-smoke, I had varied and confirmed in many ways those experiments on neutral points, when my attention was drawn by Sir Charles Wheatstone to an important observation communicated to the Paris Academy in 1860 by Professor Govi, of Turin.[1] M. Govi had been led to examine a beam of light sent through a room in which was diffused the smoke of incense, and tobacco-smoke. His first brief communication stated the fact of polarisation by such smoke; but in his second communication he announced the discovery of a neutral point in the beam, at the opposite sides of which the light was polarised in planes at right angles to each other.

But unlike my observations on the laboratory air, and unlike the action of the sky, the direction of maximum polarisation in M. Govi's experiment enclosed a very small angle with the axis of the illuminating beam. The question was left in this condition, and I am not aware that M. Govi or any other investigator has pursued it further.

I had noticed, as before stated, that as the clouds formed in the experimental tube became denser, the polarisation of the light discharged at right angles to the beam became weaker, the direction of maximum polarisation becoming oblique to the beam. Experiments on the fumes of chloride of ammonium gave me also reason to suspect that the position of the neutral point *was not constant*, but that it varied with the density of the illuminated fumes.

The examination of these questions led to the following new and remarkable results: The laboratory being well filled with the fumes of incense, and sufficient time being allowed for their uniform diffusion, the electric beam was sent through the smoke. From the track of the beam polarised light was discharged; but the direction of maximum polarisation, instead of being perpendicular, now enclosed an angle of only 12° or 13° with the axis of the beam.

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[1] '*Comptes Rendus*,' tome li. pp. 360 and 669.

A neutral point, with complementary effects at opposite sides of it, was also exhibited by the beam. The angle enclosed by the axis of the beam, and a line drawn from the neutral point to the observer's eye, measured in the first instance 66°.

The windows of the laboratory were now opened for some minutes, a portion of the incense-smoke being permitted to escape. On again darkening the room and turning on the light, the line of vision to the neutral point was found to enclose, with the axis of the beam, an angle of 63°.

The windows were again opened for a few minutes, more of the smoke being permitted to escape. Measured as before, the angle referred to was found to be 54°.

This process was repeated three additional times; the neutral point was found to recede lower and lower down the beam, the angle between a line drawn from the eye to the neutral point and the axis of the beam falling successively from 54° to 49°, 43° and 33°.

The distances, roughly measured, of the neutral point from the lamp, corresponding to the foregoing series of observations, were these:—

1st observation	2 feet	2 inches.
2nd ,,	2 ,,	6 ,,
3rd ,,	2 ,,	10 ,,
4th ,,	3 ,,	2 ,,
5th ,,	3 ,,	7 ,,
6th ,,	4 ,,	6 ,,

At the end of this series of experiments the direction of maximum polarisation had again become normal to the beam.

The laboratory was next filled with the fumes of gunpowder. In five successive experiments, corresponding to five different densities of the gunpowder-smoke, the angles enclosed between the line of vision to the neutral point, and the axis of the beam, were 63°, 50°, 47°, 42°, and 38° respectively.

After the clouds of gunpowder had cleared away the laboratory was filled with the fumes of common resin, rendered so dense as to be very irritating to the lungs. The direction of maximum polarisation enclosed, in this case, an angle of 12°, or thereabouts, with the axis of the beam. Looked at, as in the former instances, from a position near the electric lamp, *no neutral point* was observed throughout the entire extent of the beam.

When this beam was looked at normally through the selenite and Nicol, the ring-system, though not brilliant, was distinct. Keeping the eye upon the plate of selenite, and the line of vision perpendicular, the windows were opened, the blinds remaining undrawn. The resinous fumes slowly diminished, and as they did so the ring-system became paler. It finally disappeared. Continuing to look in the same direction, the rings revived, but now the colours were complementary to the former ones. *The neutral point had passed me in its motion down the beam, consequent upon the attenuation of the fumes of resin.*

With the fumes of chloride of ammonium substantially the same results were obtained. Sufficient, however, has been here stated to illustrate the variability of the position of the neutral point.[1]

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[1] Brewster has proved the variability of the position of the neutral point for skylight with the sun's altitude, a result obviously connected with the foregoing experiments.

Some of the clouds formed in the experiments on the chemical action of light are, as already stated, astonishing as to shape. The experimental tube is often divided into segments of dense cloud, separated from each other by nodes of finer matter. Looked at normally, as many as four reversals of the plane of polarisation have been found, in passing from node to segment, and from segment to node. With the fumes diffused in the laboratory, on the contrary, there was no change in the polarisation along the normal, for here the necessary differences of cloud-texture did not exist.

By a puff of tobacco-smoke, or of condensed steam, blown into the illuminated beam, the brilliancy of the selenite colours may be greatly augmented. But with different clouds two different effects are produced. Let the ring-system observed in the common air be brought to its maximum strength, and then let an attenuated cloud of chloride of ammonium be thrown into the beam at the point looked at; the ring-system flashes out with augmented brilliancy, but the character of the polarisation remains unchanged. This is also the case when phosphorus, or sulphur, is burned underneath the beam, so as to cause the fine particles of phosphoric acid or of sulphur to rise into the light. With the sulphur-fumes the brilliancy of the colours is exceedingly intensified; but in none of these cases is there any change in the character of the polarisation.

But when a puff of aqueous cloud, or of the fumes of hydrochloric acid, hydriodic acid, or nitric acid is thrown into the beam, there is a complete reversal of the selenite tints. Each of these clouds twists the plane of polarisation 90°. On these and kindred points experiments are still in progress.[1]

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[1] Sir John Herschel suggested to me that this change of the polarisation from positive to negative may indicate a change from polarisation

Almost all liquids have motes in them sufficiently numerous to polarise sensibly the light, and very beautiful effects may be obtained by simple artificial devices. When, for example, a cell of distilled water is placed in front of the electric lamp, and a thin slice of the beam is permitted to pass through it, scarcely any polarised light is discharged, and scarcely any colour produced with a plate of selenite. But if a bit of soap be agitated in the water above the beam, the moment the infinitesimal particles reach the light the liquid sends forth laterally almost perfectly polarised light; and if the selenite be employed, vivid colours flash into existence. A still more brilliant result is obtained with mastic dissolved in a great excess of alcohol.

The selenite rings, in fact, constitute an extremely delicate test as to the quantity of individually invisible particles in a liquid. Commencing with distilled water, for example, a thick slice of light is necessary to make the polarisation of its suspended particles sensible. A much thinner slice suffices for common water; while, with Brücke's precipitated mastic, a slice too thin to produce any sensible effect with most other liquids, suffices to bring out vividly the selenite colours.

§ 3. The Sky of the Alps.

The vision of an object always implies a differential action on the retina of the observer. The object is distinguished from surrounding space by its excess or defect of light in relation to that space. By altering the illumination, either of the object itself or of its environment, we alter the appearance of the object. Take the case of clouds floating in the atmosphere with patches of

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by reflection to polarisation by refraction. This thought repeatedly occurred to me while looking at the effects; but it will require much following up before it emerges into clearness.

blue between them. Anything that changes the illumination of either alters the appearance of both, that appearance depending, as stated, upon differential action. Now the light of the sky, being polarised, may, as the reader of the foregoing pages knows, be in great part quenched by a Nicol's prism, while the light of a common cloud, being unpolarised, cannot be thus extinguished. Hence the possibility of very remarkable variations, not only in the aspect of the firmament, which is really changed, but also in the aspect of the clouds, which have that firmament as a blackground. It is possible, for example, to choose clouds of such a depth of shade that when the Nicol quenches the light behind them, they shall vanish, being undistinguishable from the residual dull tint which outlives the extinction of the brilliancy of the sky. A cloud less deeply shaded, but still deep enough, when viewed with the naked eye, to appear dark on a bright ground, is suddenly changed to a white cloud on a dark ground by the quenching of the light behind it. When a reddish cloud at sunset chances to float in the region of maximum polarisation, the quenching of the surrounding light causes it to flash with a brighter crimson. Last Easter eve the Dartmoor sky, which had just been cleansed by a snow-storm, wore a very wild appearance. Round the horizon it was of steely brilliancy, while reddish cumuli and cirri floated southwards. When the sky was quenched behind them these floating masses seemed like dull embers suddenly blown upon; they brightened like a fire. In the Alps we have the most magnificent examples of crimson clouds and snows, so that the effects just referred to may be here studied under the best possible conditions. On August 23, 1869, the evening Alpenglow was very fine, though it did not reach its maximum depth and splendour. The side of the Weisshorn seen from the Bel Alp, being turned from the sun, was tinted *mauve*; but I wished to observe one of the rose-coloured buttresses of the mountain. Such was visible from a point a few hundred feet above the hotel. The Matterhorn also, though for the most part in shade, had a crimson projection, while a deep ruddy red lingered along its western shoulder. Four distinct peaks and buttresses of the Dom, in addition to its dominant head—all covered with pure snow—were reddened by the light of sunset. The shoulder of the Alphubel was similarly coloured, while the great mass of the Fletschorn was all a-glow, and so was the snowy spine of the Monte Leone.

Looking at the Weisshorn through the Nicol, the glow of its protuberance was strong or weak according to the position of the prism. The summit also underwent striking changes. In one position of the prism it exhibited a pale white against a dark background; in the rectangular position it was a dark mauve against a light background. The red of the Matterhorn changed in a similar manner; but the whole mountain also passed through wonderful changes of definition. The air at the time was filled with a silvery haze, in which the Matterhorn almost disappeared. This could be wholly quenched by the Nicol, and then the mountain sprang forth with astonishing solidity and detachment from the surrounding air. The changes of the Dom were still more wonderful. A vast amount of light could be removed from the sky behind it, for it occupied the position of maximum polarisation. By a little practice with the Nicol it was easy to render the extinction of the light, or its restoration, almost instantaneous. When the sky was quenched, the four minor peaks and buttresses, and the summit of the Dom, together with the shoulder of the Alphubel, glowed as if set suddenly on fire. This was immediately dimmed by turning the Nicol through an angle of 90°.

It was not the stoppage of the light of the sky behind the mountains alone which produced this startling effect; the air between them and me was highly opalescent, and the quenching of this intermediate glare augmented remarkably the distinctness of the mountains.

On the morning of August 24 similar effects were finely shown. At 10 A.M. all three mountains, the Dom, the Matterhorn, and the Weisshorn, were powerfully affected by the Nicol. But in this instance also, the line drawn to the Dom being very nearly perpendicular to the solar beams, the effects on this mountain were most striking. The grey summit of the Matterhorn, at the same time, could scarcely be distinguished from the opalescent haze around it; but when the Nicol quenched the haze, the summit became instantly isolated, and stood out in bold definition. It is to be remembered that in the production of these effects the only things changed are the sky behind, and the luminous haze in front of the mountains; that these are changed because the light emitted from the sky and from the haze is plane polarised light, and that the light from the snows and from the mountains, being sensibly unpolarised, is not directly affected by the Nicol. It will also be understood that it is not the interposition of the haze *as an opaque body* that renders the mountains indistinct, but the *light* of the haze which dims and bewilders the eye, and thus weakens the definition of objects seen through it.

These results have a direct bearing upon what artists call 'aërial perspective.' As we look from the summit of Mont Blanc, or from a lower elevation, at the serried crowd of peaks, especially if the mountains be darkly coloured—covered with pines, for example—every peak and ridge is separated from the mountains behind it by a thin blue haze which renders the relations of the mountains as to distance unmistakable. When this haze is regarded through the Nicol perpendicular to the sun's rays, it is in many cases wholly quenched, because the light which it emits in this direction is wholly polarised. When this happens, aërial perspective is abolished, and mountains very differently distant appear to rise in the same vertical plane. Close to the Bel Alp, for instance, is the gorge of the Massa, and beyond the gorge is a high ridge darkened by pines. This ridge may be projected upon the dark slopes at the opposite side of the Rhone valley, and between both we have the blue haze referred to, throwing the distant mountains far away. But at certain hours of the day the haze may be quenched, and then the Massa ridge and the mountains beyond the Rhone seem almost equally distant from the eye. The one appears, as it were, a vertical continuation of the other. The haze varies with the temperature and humidity of the atmosphere. At certain times and places it is almost as blue as the sky itself; but to see its colour, the attention must be withdrawn from the mountains and from the trees which cover them. In point of fact, the haze is a piece of more or less perfect sky; it is produced in the same manner, and is subject to the same laws, as the firmament itself. We live *in* the sky, not *under* it.

These points were further elucidated by the deportment of the selenite plate, with which the readers of the foregoing pages are so well acquainted. On some of the sunny days of August the haze in the valley of the Rhone, as looked at from the Bel Alp, was very remarkable. Towards evening the sky above the mountains opposite to my place of observation yielded a series of the most splendidly-coloured iris-rings; but on lowering the selenite until it had the darkness of the pines at the opposite side of the Rhone valley, instead of the darkness of space, as a background, the colours were not much diminished in brilliancy. I should estimate the distance across the valley, as the crow flies, to the opposite mountain, at nine miles; so that a body of air of this thickness can, under favourable circumstances, produce chromatic effects of polarisation almost as vivid as those produced by the sky itself.

Again: the light of a landscape, as of most other things, consists of two parts; the one, coming purely from superficial reflection, is always of the same colour as the light which falls upon the landscape; the other part reaches us from a certain depth within the objects which compose the landscape, and it is this portion of the total light which gives these objects their distinctive colours. The white light of the sun enters all substances to a certain depth, and is partially ejected by internal reflection; each distinct substance absorbing and reflecting the light, in accordance with the laws of its own molecular constitution. Thus the solar light is *sifted* by the landscape, which appears in such colours and variations of colour as, after the sifting process, reach the observer's eye. Thus the bright green of grass, or the darker colour of the pine, never comes to us alone, but is always mingled with an amount of really foreign light derived from superficial reflection. A certain hard brilliancy is conferred upon the woods and meadows by this superficially-reflected light. Under certain circumstances, it may be quenched by a Nicol's prism, and we then obtain the true colour of the grass and foliage. Trees and meadows, thus regarded, exhibit a richness and softness of tint which they never show as long as the superficial light is permitted to mingle with the true interior emission. The needles of the pines show this effect very well, large-leaved trees still better; while a glimmering field of maize exhibits the most extraordinary variations when looked at through the rotating Nicol.

Thoughts and questions like those here referred to took me, in August 1869, to the top of the Aletschhorn. The effects described in the foregoing paragraphs were for the most part reproduced in the summit of the mountain. I scanned the whole of the sky with my Nicol. Both alone, and in conjunction with the selenite, it pronounced the perpendicular to the solar beams to be the direction of maximum polarisation. But at no portion of the firmament was the polarisation complete. The artificial sky produced in the experiments recorded in the preceding pages could, in this respect, be rendered more perfect than the natural one; while the gorgeous 'residual blue' which makes its appearance when the polarisation of the artificial sky ceases to be perfect, was strongly contrasted with the lack-lustre hue which, in the case of the firmament, outlived the extinction of the brilliancy. With certain substances, however, artificially treated, this dull residue may also be obtained.

All along the arc from the Matterhorn to Mont Blanc the light of the sky immediately above the mountains was powerfully acted upon by the Nicol. In some cases the variations of intensity were astonishing. I have already said that a little practice enables the observer to shift the Nicol from one position to another so rapidly as to render the alternate extinction and restoration of the light immediate. When this was done along the arc to which I have referred, the alternations of light and darkness resembled the play of sheet lightning behind the mountains. There was an element of awe connected with the suddenness with which the mighty masses, ranged along the line referred to, changed their aspect and definition under the operation of the prism.

V.

ON DUST AND DISEASE

1870.

Experiments on Dusty Air.

SOLAR light, in passing through a dark room, reveals its track by illuminating the dust floating in the air. 'The sun,' says Daniel Culverwell, 'discovers atomes, though they be invisible by candle-light, and makes them dance naked in his beams.'

In my researches on the decomposition of vapours by light, I was compelled to remove these 'atomes' and this dust. It was essential that the space containing the vapours should embrace no visible thing—that no substance capable of scattering light in the slightest sensible degree should, at the outset of an experiment, be found in the wide 'experimental tube' in which the vapour was enclosed.

For a long time I was troubled by the appearance there of floating matter, which, though invisible in diffuse daylight, was at once revealed by a powerfully condensed beam. Two U-tubes were placed in succession in the path of the air, before it entered the liquid whose vapour was to be carried into the experimental tube. One of the U-tubes contained fragments of glass wetted with concentrated sulphuric acid; the other, fragments of marble wetted with a strong solution of caustic potash.[1] To my astonishment, the air of the Royal Institution, sent through these tubes at a rate sufficiently slow to dry it, and to remove its carbonic acid, carried into the experimental tube a considerable amount of mechanically suspended matter, which was illuminated when the beam passed through the tube. The effect was substantially the same when the air was permitted to bubble through the liquid acid, and through the solution of potash.

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[1] *The apparatus is figured and described at p. 154.*

I tried to intercept this floating matter in various ways; and on October 5, 1868, prior to sending the air through the drying apparatus, it was carefully permitted to pass over the tip of a spirit-lamp flame. The floating matter no longer appeared, having been burnt up by the flame. It was therefore *organic matter*. I was by no means prepared for this result; having previously thought that the dust of our air was, in great part, inorganic and non-combustible.[1]

I had constructed a small gas-furnace, now much employed by chemists, containing a platinum tube, which could be heated to vivid redness.[2] The tube contained a roll of platinum gauze, which, while it permitted the air to pass through it, ensured the practical contact of the dust with the incandescent metal. The air of the laboratory was permitted to enter the experimental tube, sometimes through the cold, and sometimes through the heated, tube of platinum. In the first column of the

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[1] According to an analysis kindly furnished to me by Dr. Percy, the dust collected *from the walls* of the British Museum contains fully 50 per cent. of inorganic matter. I have every confidence in the results of this distinguished chemist; they show that the *floating* dust of our rooms is, as it were, winnowed from the heavier matter. As bearing directly upon this point I may quote the following passage from Pasteur: 'Mais ici se présente une remarque: la poussière que l'on trouve à la surface de tous les corps est soumise constamment à des courants d'air, qui doivent soulever ses particules les plus légères, au nombre desquelles se trouvent, sans doute, de préférence les corpuscules organisés, œufs ou spores, moins lourds généralement que les particules minérales.'

[2] *Pasteur was, I believe, the* first to employ such a tube.

[illegible]

[illegible]

[illegible] very [illegible]

[illegible] in [illegible]

[illegible] in

[illegible] same [illegible]

[illegible] upwar

[illegible]

What, then, was the blackness? It was simply that of stellar space; that is to say, blackness resulting from the absence from the track of the beam of all matter competent to scatter its light. When the flame was placed below the beam the floating matter was destroyed *in situ*; and the air, freed from this matter, rose into the beam, jostled aside the illuminated particles, and substituted for their light the darkness due to its own perfect transparency. Nothing could more forcibly illustrate the invisibility of the agent which renders all things visible. The beam crossed, unseen, the black chasm formed by the transparent air, while, at both sides of the gap, the thick-strewn particles shone out like a luminous solid under the powerful illumination.

It is not, however, necessary to burn the particles to produce a stream of darkness. Without actual combustion, currents may be generated which shall displace the floating matter, and appear dark amid the surrounding brightness. I noticed this effect first on placing a red-hot copper ball below the beam, and permitting it to remain there until its temperature had fallen below that of boiling water. The dark currents, though much enfeebled, were still produced. They may also be produced by a flask filled with hot water.

To study this effect a platinum wire was stretched across the beam, the two ends of the wire being connected with the two poles of a voltaic battery. To regulate the strength of the current a rheostat was placed in the circuit. Beginning with a feeble current the temperature of the wire was gradually augmented; but long before it reached the heat of ignition, a flat stream of air rose from it, which when looked at edgeways appeared darker and sharper than one of the blackest lines of Fraunhofer in the purified spectrum. Right and left of this dark vertical band the floating matter rose upwards, bounding definitely the non-luminous stream of air. What is the explanation? Simply this: The hot wire rarefied the air in contact with it, but it did not equally lighten the floating matter. The convection current of pure air therefore passed upwards *among the inert particles*, dragging them after it right and left, but forming between them an impassable black partition. This elementary experiment enables us to render an account of the dark currents produced by bodies at a temperature below that of combustion.

But when the platinum wire is intensely heated, the floating matter is not only displaced, but destroyed. I stretched a wire about 4 inches long through the air of an ordinary glass shade resting on cotton-wool, which also surrounded the rim. The wire being raised to a white heat by an electric current, the air expanded, and some of it was forced through the cotton-wool. When the current was interrupted, and the air within the shade cooled, the returning air did not carry motes along with it, being filtered by the wool. At the beginning of this experiment the shade was charged with floating matter; at the end of half an hour it was optically empty.

On the wooden base of a cubical glass shade measuring 11½ inches a side, upright supports were fixed, and from one support to the other 38 inches of platinum wire were stretched in four parallel lines. The ends of the platinum wire were soldered to two stout copper wires which passed through the base of the shade and could be connected with a battery. As in the last experiment the shade rested upon cotton-wool. A beam sent through the shade revealed the suspended matter. The platinum wire was then raised to whiteness. In five minutes there was a sensible diminution of the matter, and in ten minutes it was totally consumed.

Oxygen, hydrogen, nitrogen, carbonic acid, so prepared as to exclude all floating particles, produce, when poured or blown into the beam, the darkness of stellar space. Coal-gas does the same. An ordinary glass shade, placed in the air with its mouth downwards, permits the track of the beam to be seen crossing it. When coal-gas or hydrogen is permitted to enter the shade by a tube reaching to its top, the gas gradually fills the shade from above downwards. As soon as it occupies the space crossed by the beam, the luminous track is abolished. Lifting the shade so as to bring the common boundary of gas and air above the beam, the track flashes forth. After the shade is full, if it be inverted, the pure gas passes upwards like a black smoke among the illuminated particles.

The Germ Theory of Contagious Disease.

There is no respite to our contact with the floating matter of the air: and the wonder is, not that we should suffer occasionally from its presence, but that so small a portion of it, and even that but rarely diffused over large areas, should appear to be deadly to man. And what is this portion? It was some time ago the current belief that epidemic diseases generally were propagated by a kind of malaria, which consisted of organic matter in a state of *motor-decay*; that when such matter was taken into the body through the lungs, skin, or stomach, it had the power of spreading there the destroying process by which itself had been assailed. Such a power was visibly exerted in the case of yeast. A little leaven was seen to leaven the whole lump—a mere speck of matter, in this supposed state of decomposition, being apparently competent to propagate indefinitely its own decay. Why should not a bit of rotten malaria act in a similar manner within the human frame? In 1836 a very wonderful reply was given to this question. In that year Cagniard de la Tour discovered the *yeast-plant*, a living organism, which when placed in a proper medium feeds, grows, and reproduces itself, and in this way carries on the process which we name fermentation. By this striking discovery fermentation was connected with organic growth.

Schwann, of Berlin, discovered the yeast-plant independently about the same time; and in February, 1837, he also announced the important result, that when a decoction of meat is effectually screened from ordinary air, and supplied solely with calcined air, putrefaction never sets in. Putrefaction, therefore, he affirmed to be caused, not by the air, but by something which could be destroyed by a sufficiently high temperature. The results of Schwann were confirmed by the independent experiments of Helmholtz, Ure, and Pasteur, while other methods, pursued by Schultze, and by Schroeder and Dusch, led to the same result. But as regards fermentation, the minds of chemists, influenced probably by the great authority of Gay-Lussac, fell back upon the old notion of matter in a state of decay. It was not the living yeast-plant, but the dead or dying parts of it, which, assailed by oxygen, produced the fermentation. This notion was finally exploded by Pasteur. He proved the real 'ferments' to be organised beings which find in the reputed ferments their necessary food.

Side by side with these researches and discoveries, and fortified by them and others, has run the *germ theory* of epidemic disease. The notion was expressed by Kircher, and favoured by Linnæus, that epidemic diseases may be due to germs which float in the atmosphere, enter the body, and produce disturbance by the development within the body of parasitic life. The strength of this theory consists in the perfect parallelism of the phenomena of contagious disease with those of life. As a planted acorn *gives birth to* an oak, competent to produce a whole crop of acorns, each gifted with the power of reproducing its parent tree; and as thus from a single seedling a whole forest may spring; so, it is contended, these epidemic diseases literally plant their seeds, grow, and shake abroad new germs, which, meeting in the human body their proper food and temperature, finally takes possession of whole populations. There is nothing to my knowledge in pure chemistry which resembles the power of self-multiplication possessed by the matter which produces epidemic disease. If you sow wheat you do not get barley; if you sow small-pox you do not get scarlet-fever, but small-pox indefinitely multiplied, and nothing else. The matter of each contagious disease reproduces itself as rigidly as if it were (as Miss Nightingale puts it) dog or cat.

Parasitic Diseases of Silkworms. Pasteur's Researches.

It is admitted on all hands that some diseases are the product of parasitic growth. Both in man and in lower creatures, the existence of such diseases has been demonstrated. I am enabled to lay before you an account of an epidemic of this kind, thoroughly investigated and successfully combated by M. Pasteur. For fifteen years a plague had raged among the silkworms of France. They had sickened and died in multitudes, while those that succeeded in spinning their cocoons furnished only a fraction of the normal quantity of silk. In 1853 the silk culture of France produced a revenue of one hundred and thirty millions of francs. During the twenty previous years the revenue had doubled itself, and no doubt was entertained as to its further augmentation. The weight of the cocoons produced in 1853 was 26,000,000 kilogrammes; in 1865 it had fallen to 4,000,000, the fall entailing, in a single year, a loss of 100,000,000 francs.

The country chiefly smitten by this calamity happened to be that of the celebrated chemist Dumas, now perpetual secretary of the French Academy of Sciences. He turned to his friend, colleague, and pupil, Pasteur, and besought him, with an earnestness which the circumstances rendered almost personal, to undertake the investigation of the malady. Pasteur at this time had never seen a silkworm, and he urged his inexperience in reply to his friend. But Dumas knew too well the qualities needed for such an enquiry to accept Pasteur's reason for declining it. 'Je mets,' said he, 'un prix extrême à voir votre attention fixée sur la question qui intéresse mon pauvre pays; la misère surpasse tout ce que vous pouvez imaginer.' Pamphlets about the plague had been showered upon the public, the monotony of waste paper being broken, at rare intervals, by a more or less useful publication. 'The Pharmacopœia of the Silkworm,' wrote M. Cornalia in 1860, 'is now as complicated as that of man. Gases, liquids, and solids have been laid under contribution. From chlorine to sulphurous acid, from nitric acid to rum, from sugar to sulphate of quinine,—all has been invoked in behalf of this unhappy insect.' The helpless cultivators, moreover, welcomed with ready trustfulness every new remedy, if only pressed upon them with sufficient hardihood. It seemed impossible to diminish their blind confidence in their blind guides. In 1863 the French Minister of Agriculture signed an agreement to pay 500,000 francs for the use of a remedy, which its promoter declared to be infallible. It was tried in twelve different departments of France, and found perfectly useless. In no single instance was it successful. It was under these circumstances that M. Pasteur, yielding to the entreaties of his friend, betook himself to Alais in the beginning of June, 1865. As regards silk husbandry, this was the most important department in France, and it was the most sorely smitten by the plague.

The silkworm had been previously attacked by *mus-*

cardine, a disease proved by Bassi to be caused by a vegetable parasite. Though not hereditary, this malady was propagated annually by the parasitic spores. Wafted by winds they often sowed the disease in places far removed from the centre of infection. Muscardine is now said to be very rare, a deadlier malady having taken its place. A frequent outward sign of this new disease are the black spots which cover the silkworms; hence the name *pébrine*, first applied to the plague by M. de Quatrefages, and adopted by Pasteur. Pébrine declares itself in the stunted and unequal growth of the worms, in the languor of their movements, in their fastidiousness as regards food, and in their premature death. The track of discovery as regards the epidemic is this: In 1849 Guerin Méneville noticed in the blood of silkworms vibratory corpuscles, which he supposed to be endowed with independent life. Filippi proved him wrong, and showed that the motion of the corpuscles was the well-known Brownian motion. But Filippi himself committed the error of supposing the corpuscles to be normal to the life of the insect. They are really the cause of its mortality—the form and substance of its disease. This was well described by Cornalia; while Lebert and Frey subsequently found the corpuscles not only in the blood, but in all the tissues of the insect. Osimo, in 1857, discovered them in the eggs; and on this observation Vittadiani founded, in 1859, a practical method of distinguishing healthy from diseased eggs. The test often proved fallacious, and it was never extensively applied.

These living corpuscles take possession of the intestinal canal, and spread thence throughout the body of the worm. They fill the silk cavities, the stricken insect often going automatically through the motions of spinning, without any material to work upon. Its organs, instead of being filled with the clear viscous liquid of the silk, are packed to distension by the corpuscles. On this feature of the plague Pasteur fixed his entire attention. The cycle of the silkworm's life is briefly this: From the fertile egg comes the little worm, which grows, and casts its skin. This process of moulting is repeated two or three times at subsequent intervals during the life of the insect. After the last moulting the worm climbs the brambles placed to receive it, and spins among them its cocoon. It passes thus into a chrysalis; the chrysalis becomes a moth, and the moth, when liberated, lays the eggs which form the starting-point of a new cycle. Now Pasteur proved that the plague-corpuscles might be incipient in the egg, and escape detection; they might also be germinal in the worm, and still baffle the microscope. But as the worm grows, the corpuscles grow also, becoming larger and more defined. In the aged chrysalis they are more pronounced than in the worm; while in the moth, if either the egg or the worm from which it comes should have been at all stricken, the corpuscles infallibly appear, offering no difficulty of detection. This was the first great point made out in 1865 by Pasteur. The Italian naturalists, as aforesaid, recommended the examination of the eggs before risking their incubation. Pasteur showed that both eggs and worms might be smitten, and still pass muster, the culture of such eggs or such worms being sure to entail disaster. He made the moth his starting-point in seeking to regenerate the race.

Pasteur made his first communication on this subject to the Academy of Sciences in September, 1865. It raised a cloud of criticism. Here, forsooth, was a chemist rashly quitting his proper *métier* and presuming to lay down the law for the physician and biologist on a subject which was eminently theirs. 'On trouva étrange que je fusse si peu au courant de la question; on m'opposa des travaux *qui avaient* paru depuis longtemps en Italie, dont les résultats montraient l'inutilité de mes efforts, et l'impossibilité d'arriver à un résultat pratique dans la direction que je m'étais engagé. Que mon ignorance fut grande au sujet des recherches sans nombre qui avaient paru depuis quinze années.' Pasteur heard the buzz, but he continued his work. In choosing the eggs intended for incubation, the cultivators selected those produced in the successful 'educations' of the year. But they could not understand the frequent and often disastrous failures of their selected eggs; for they did not know, and nobody prior to Pasteur was competent to tell them, that the finest cocoons may envelope doomed corpusculous moths. It was not, however, easy to make the cultivators accept new guidance. To strike their imagination, and if possible determine their practice, Pasteur hit upon the expedient of prophecy. In 1866 he inspected, at St. Hippolyte-du-Fort, fourteen different parcels of eggs intended for incubation. Having examined a sufficient number of the moths which produced these eggs, he wrote out the prediction of what would occur in 1867, and placed the prophecy as a sealed letter in the hands of the Mayor of St. Hippolyte.

In 1867 the cultivators communicated to the mayor their results. The letter of Pasteur was then opened and read, and it was found that in twelve out of fourteen cases there was absolute conformity between his prediction and the observed facts. Many of the groups had perished totally; the others had perished almost totally; and this was the prediction of Pasteur. In two out of the fourteen cases, instead of the prophesied destruction, half an average crop was obtained. Now, the parcels of eggs here referred to were considered healthy by their owners. They had been hatched and tended in the firm hope that the labour expended on them would prove remunerative. The application of the moth-test for a few minutes in 1866, would have saved the labour and averted the disappointment. Two additional parcels of eggs were at the same time submitted to Pasteur. He pronounced them healthy; and his words were verified by the production of an excellent crop. Other cases of prophecy still more remarkable, because more circumstantial, are recorded in Pasteur's work.

Pasteur subjected the development of the corpuscles to a searching investigation, and followed out with admirable skill and completeness the various modes by which the plague was propagated. From moths perfectly free from corpuscles he obtained healthy worms, and selecting 10, 20, 30, 50, as the case might be, he introduced into the worms the corpusculous matter. It was first permitted to accompany the food. Let us take a single example out of many. Rubbing up a small corpusculous worm in water, he smeared the mixture over the mulberry-leaves. Assuring himself that the leaves had been eaten, he watched the consequences from day to day. Side by side with the infected worms he reared their fellows, keeping them as much as possible out of the way of infection. These constituted his 'lot temoign,'—his standard of comparison. On April 16, 1868, he thus infected thirty worms. Up to the 23rd they remained quite well. On the 25th they seemed well, but on that day corpuscles were found in the intestines of two of them. On the 27th, or eleven days after the infected repast, two fresh worms were examined, and not only was the intestinal canal found in each case invaded, but the silk organ itself was charged with corpuscles. On the 28th the twenty-six remaining worms were covered by the black spots of pébrine. On the 30th the difference of size between the infected and non-infected worms was very striking, the sick worms being not more than two-thirds of the bulk of the healthy ones. On May 2 a worm which had just finished its fourth moulting was examined. Its whole body was so filled with the parasite as to excite astonishment that it could live. The disease advanced, the worms died and were examined, and on May 11 only six out of the thirty remained. They were the strongest of the lot, but on being searched they also were found charged with corpuscles. Not one of the thirty worms had escaped; a single meal had poisoned them all. The standard lot, on the contrary, spun their fine cocoons, two only of their moths being proved to contain any trace of the parasite, which had doubtless been introduced during the rearing of the worms.

As his acquaintance with the subject increased, Pasteur's desire for precision augmented, and he finally counted the growing number of corpuscles seen in the field of his microscope from day to day. After a contagious repast the number of worms containing the parasite gradually augmented until finally it became cent. per cent. The number of corpuscles would at the same time rise from 0 to 1, to 10, to 100, and sometimes even to 1,000 or 1,500 in the field of his microscope. He then varied the mode of infection. He inoculated healthy worms with the corpusculous matter, and watched the consequent growth of the disease. He proved that the worms inoculate each other by the infliction of visible wounds with their claws. In various cases he washed the claws, and found corpuscles in the water. He demonstrated the spread of infection by the simple association of healthy and diseased worms. By their claws and their dejections, the diseased worms spread infection. It was no hypothetical infected medium — no problematical pythogenic gas—that killed the worms, but a definite organism. The question of infection at a distance was also examined, and its existence demonstrated. As might be expected from Pasteur's antecedents, the investigation was exhaustive, the skill and beauty of his manipulation finding fitting correlatives in the strength and clearness of his thought.

The following quotation from Pasteur's work clearly shows the relation in which his researches stand to the important question on which he was engaged:

> Place (he says) the most skilful educator, even the most expert microscopist, in presence of large educations which present the symptoms described in our experiments; his judgment will necessarily be erroneous if he confines himself to the knowledge which preceded my researches. The worms will not present to him the slightest spot of pébrine; the microscope will not reveal the existence of corpuscles; the mortality of the worms will be null or insignificant; and the cocoons leave nothing to be desired. Our observer would, therefore, conclude without hesitation that the eggs produced will be good for incubation. The truth is, on the contrary, that all the worms of these fine crops have been poisoned; that from the beginning they carried in them the germ of the malady; ready to multiply itself beyond measure in the chrysalides and the moths, thence to pass into the eggs and smite with sterility the next generation. And what is the first cause of the evil concealed under so deceitful an exterior? In our experiments we can, so to speak, touch it with our fingers. It is entirely the effect of a single corpusculous repast; an effect more or less prompt according to the epoch of life of the worm that has eaten the poisoned food.

Pasteur describes in detail his method of securing healthy eggs. It is nothing less than a mode of restoring to France her ancient silk husbandry. The justification of his work is to be found in the reports which reached him of the application and the unparalleled success of his method, while editing his researches for final publication. In both France and Italy his method has been pursued with the most surprising results. But it was an up-hill fight which led to this triumph. 'Ever,' he says, 'since the commencement of these researches, I have been exposed to the most obstinate and unjust contradictions; but I have made it a duty to leave no trace of these conflicts in this book.' And in reference to parasitic diseases, generally, he uses the following weighty words: 'Il est au pouvoir de l'homme de faire disparaître de la surface du globe les maladies parasitaires, si, comme c'est ma conviction, la doctrine des générations spontanées est une chimère.'

Pasteur dwells upon the ease with which an island like Corsica might be absolutely isolated from the silkworm epidemic. And with regard to other epidemics, Mr. Simon describes an extraordinary case of insular exemption, for the ten years extending from 1851 to 1860. Of the 627 registration districts of England, one only had an entire escape from diseases which, in whole or in part, were prevalent in all the others: 'In all the ten years it had not a single death by measles, nor a single death by small-pox, nor a single death by scarlet-fever. And why? Not because of its general sanitary merits, for it had an average amount of other evidence of unhealthiness. Doubtless, the reason of its escape was that it was insular. It was the *district of the Scilly Isles;* to which it was most improbable that any febrile contagion should come from without. And its escape is an approximative proof that, at least for those ten years, no contagium of measles, nor any contagium of scarlet-fever, nor any contagium of small-pox had arisen spontaneously within its limits.' It may be added that there were only seven districts in England in which no death from diphtheria occurred, and that, of those seven districts, the district of the Scilly Isles was one.

A second parasitic disease of silkworms, called in France *la flacherie*, co-existent with pébrine, but quite distinct from it, has also been investigated by Pasteur. Enough, however, has been said to send the reader interested in these questions to the original volumes for further information. To one important practical point M. Pasteur, in a letter to myself, directs attention :

> Permettez-moi de terminer ces quelques lignes que je dois dicter, vaincu que je suis par la maladie, en vous faisant observer que vous rendriez service aux Colonies de la Grande-Bretagne en répandant la connaissance de ce livre, et des principes que j'établis touchant la maladie des vers à soie. Beaucoup de ces colonies pourraient cultiver le mûrier avec succès, et en jetant les yeux sur mon ouvrage vous vous convaincrez aisément qu'il est facile aujourd'hui, non-seulement d'éloigner la maladie régnante, mais en outre de donner aux récoltes de la soie une prospérité qu'elles n'ont jamais eue.

Origin and Propagation of Contagious Matter.

Prior to Pasteur, the most diverse and contradictory opinions were entertained as to the contagious character of pébrine; some stoutly affirmed it, others as stoutly denied it. But on one point all were agreed. 'They believed in the existence of a deleterious medium, rendered epidemic by some occult and mysterious influence, to which was attributed the cause of the disease.' Those acquainted with our medical literature will not fail to observe an instructive analogy here. We have on the one side accomplished writers ascribing epidemic diseases to 'deleterious media' which arise spontaneously in crowded hospitals and ill-smelling drains. According to them, the *matter* of epidemic disease is formed *de novo* in a putrescent atmosphere. On the other side we have writers, clear, vigorous, with well-defined ideas and methods of research, contending that the matter which produces epidemic disease comes always from a parent stock. It behaves as germinal matter, and they do not hesitate to regard it as such. *They no* more believe in the spontaneous generation of such diseases, than they do in the spontaneous generation of mice. Pasteur, for example, found that pébrine had been known for an indefinite time as a disease among silkworms. The development of it which he combated was merely the expansion of an already existing power—the bursting into open conflagration of a previously smouldering fire. There is nothing surprising in this. For though epidemic disease requires a special contagium to produce it, surrounding conditions must have a potent influence on its development. Common seeds may be duly sown, but the conditions of temperature and moisture may be such as to restrict, or altogether prevent, the subsequent growth. Looked at, therefore, from the point of view of the germ theory, the exceptional energy which epidemic disease from time to time exhibits, is in harmony with the method of Nature. We sometimes hear diphtheria spoken of as if it were a new disease of the last twenty years; but Mr. Simon tells me that about three centuries ago tremendous epidemics of it began to rage in Spain (where it was named *Garrotillo*), and soon afterwards in Italy; and that since that time the disease has been well known to all successive generations of doctors. In or about 1758, for instance, Dr. Starr, of Liskeard, in a communication to the Royal Society, particularly described the disease, with all the characters which have recently again become familar, but under the name of *morbus strangulatorius*, as then severely epidemic in Cornwall. This fact is the more interesting, as diphtheria, in its more modern reappearance, again showed predilection for that remote county. Many also believe that the Black Death, of five centuries ago, has disappeared as mysteriously as it came; but Mr. Simon finds that it is believed to be prevalent at this hour in some of the north-western parts of India.

Let me here state an item of my own experience. When

eminence of
was difficult to imagine how scarlet-fev
wafted to the place. A drain ran close
on it his suspicions were manifestly fix
medical writers would fortify him in thi
deflect him from the truth, while those
would deny to a drain, however foul, t
ducing a specific disease. After close
lected that a hobby-horse had been used
and another who, a short time previo
through scarlet-fever.

Drains and cesspools, indeed, are by n
evil odour as they used to be. A fetid T
death-rate occur from time to time togeth
For, if the special matter or germs of ep
be not present, a corrupt atmosphere, ho
otherwise, will not produce the disorde
germs be present, defective drains and c
the potent distributors of disease and de
air may promote an epidemic, but cannot
the other hand, through the transport of
or virus, disease may develop itself

be carried in the pocket and sown. Hildebrand, to whose remarkable work, 'Du Typhus contagieux,' Dr. de Mussy has directed my attention, gives the following striking case, both of the durability and the transport of the virus of scarlatina: 'Un habit noir que j'avais en visitant une malade attaquée de scarlatine, et que je portai de Vienne en Podolie, sans l'avoir mis depuis plus d'un an et demi, me communiqua, dès que je fus arrivé, cette maladie contagieuse, que je répandis ensuite dans cette province, où elle était jusqu'alors presque inconnue.' Some years ago Dr. de Mussy himself was summoned to a country house in Surrey, to see a young lady who was suffering from a dropsy, evidently the consequence of scarlatina. The original disease, being of a very mild character, had been quite overlooked; but circumstances were recorded which could leave no doubt upon the mind as to the nature and cause of the complaint. But then the question arose, How did the young lady catch the scarlatina? She had come there on a visit two months previously, and it was only after she had been a month in the house that she was taken ill. The housekeeper at length cleared up the mystery. The young lady, on her arrival, had expressed a wish to occupy a room in an isolated tower. Her desire was granted; and in that room, six months previously, a visitor had been confined with an attack of scarlatina. The room had been swept and whitewashed, but the carpets had been permitted to remain.

Thousands of cases could probably be cited in which the disease has shown itself in this mysterious way, but where a strict examination has revealed its true parentage and extraction. Is it, then, philosophical to take refuge in the fortuitous concourse of atoms as a cause of specific disease, merely because in special cases the parentage may be indistinct? Those best acquainted with atomic nature, and who are most ready to admit, as regards even higher things than this, the potentialities of matter, will be the last to accept these rash hypotheses.

The Germ Theory applied to Surgery.

Not only medical but surgical science is now seeking light and guidance from this germ theory. Upon it the antiseptic system of Professor Lister of Edinburgh is founded. As already stated, the germ theory of putrefaction was started by Schwann, but the illustrations of this theory adduced by Professor Lister are of such public moment as not only to justify, but to render imperative, their introduction here.

> Schwann's observations (says Professor Lister) did not receive the attention which they appeared to me to have deserved. The fermentation of sugar was generally allowed to be occasioned by the *torula cerevisiæ*; but it was not admitted that putrefaction was due to an analogous agency. And yet the two cases present a very striking parallel. In each a stable chemical compound, sugar in the one case, albumen in the other, undergoes extraordinary chemical changes under the influence of an excessively minute quantity of a substance which, regarded chemically, we should suppose inert. As an example of this in the case of putrefaction, let us take a circumstance often witnessed in the treatment of large chronic abscesses. In order to guard against the access of atmospheric air, we used to draw off the matter by means of a canula and trocar, such as you see here, consisting of a silver tube with a sharp-pointed steel rod fitted into it, and projecting beyond it. The instrument, dipped in oil, was thrust into the cavity of the abscess, the trocar was withdrawn, and the pus flowed out through the canula, care being taken by gentle pressure over the part to prevent the possibility of regurgitation. The canula was then drawn out with due precaution against the reflux of air. This method was frequently successful as to its immediate object, the patient being relieved from the mass of the accumulated fluid, and experiencing no inconvenience from the operation. But the pus was pretty certain to reaccumulate in course of time, and it became necessary again and again to repeat the process. And unhappily there was no absolute

security of immunity from bad consequences. However carefully the procedure was conducted, it sometimes happened, even though the puncture seemed healing by first intention, that feverish symptoms declared themselves in the course of the first or second day, and, on inspecting the seat of the abscess, the skin was perhaps seen to be red, implying the presence of some cause of irritation, while a rapid reaccumulation of the fluid was found to have occurred. Under these circumstances, it became necessary to open the abscess by free incision, when a quantity large in proportion to the size of the abcess, say, for example, a quart, of pus escaped, fetid from putrefaction. Now, how had this change been brought about? Without the germ theory, I venture to say, no rational explanation of it could have been given. It must have been caused by the introduction of something from without. Inflammation of the punctured wound, even supposing it to have occurred, would not explain the phenomenon. For mere inflammation, whether acute or chronic, though it occasions the formation of pus, does not induce putrefaction. The pus originally evacuated was perfectly sweet, and we know of nothing to account for the alteration in its quality but the influence of something derived from the external world. And what could that something be? The dipping of the instrument in oil, and the subsequent precautions, prevented the entrance of oxygen. Or even if you allowed that a few atoms of the gas did enter, it would be an extraordinary assumption to make that these could in so short a time effect such changes in so large a mass of albuminous material. Besides, the pyogenic membrane is abundantly supplied with capillary vessels, through which arterial blood, rich in oxygen, is perpetually flowing; and there can be little doubt that the pus, before it was evacuated at all, was liable to any action which the element might be disposed to exert upon it.

On the oxygen theory, then, the occurrence of putrefaction under these circumstances is quite inexplicable. But if you admit the germ theory, the difficulty vanishes at once. The canula and trocar having been lying exposed to the air, dust will have been deposited upon them, and will be present in the angle between the trocar and the silver tube, and in that protected situation will fail to be wiped off when the instrument is thrust through the tissues. Then when the trocar is withdrawn, some portions of this dust will naturally remain upon the margin of the canula, which is left projecting into the abscess, and nothing is more likely than that some particles may fail to be washed off by the stream of out-flowing pus, but may be dislodged when the tube is taken out, and left behind in the cavity. The germ theory tells us that these particles of dust will be pretty sure to contain the germs of putrefactive organisms, and if one such is left in the albuminous liquid, it will rapidly develop at the high temperature of the body, and account for all the phenomena.

But striking as is the parallel between putrefaction in this instance and the vinous fermentation, as regards the greatness of the effect produced, compared with the minuteness and the inertness, chemically speaking, of the cause, you will naturally desire further evidence of the similarity of the two processes. You can see with the microscope the torula of fermenting must or beer. Is there, you may ask, any organism to be detected in the putrefying pus? Yes, gentlemen, there is. If any drop of the putrid matter is examined with a good glass, it is found to be teeming with myriads of minute jointed bodies, called vibrios, which indubitably proclaim their vitality by the energy of their movements. It is not an affair of probability, but a fact, that the entire mass of that quart of pus has become peopled with living organisms as the result of the introduction of the canula and trocar; for the matter first let out was as free from vibrios as it was from putrefaction. If this be so, the greatness of the chemical changes that have taken place in the pus ceases to be surprising. We know that it is one of the chief peculiarities of living structures that they possess extraordinary powers of effecting chemical changes in materials in their vicinity, out of all proportion to their energy as mere chemical compounds. And we can hardly doubt that the animalcules which have been developed in the albuminous liquid, and have grown at its expense, must have altered its constitution, just as we ourselves alter that of the materials on which we feed.[1]

In the operations of Professor Lister care is taken that every portion of tissue laid bare by the knife shall be defended from germs; that if they fall upon the wound they shall be killed as they fall. With this in view he showers upon his exposed surfaces the spray of diluted carbolic acid, which is particularly deadly to the germs, and he surrounds the wound in the most careful manner with antiseptic bandages. To those accustomed to strict experiment it is manifest that we have a strict experimenter here—a man with a perfectly distinct object in view, which he pursues with never-tiring patience and unwavering faith. And the result, in his hospital practice, as described by himself, has been, that even in the midst of abominations too shocking to be mentioned here, and in the neighbourhood of wards where death was rampant from pyæmia, erysipelas, and hospital gangrene, he was able to keep his patients absolutely free from these terrible scourges. Let me here recommend to your attention Professor Lister's 'Introductory Lecture before the University of Edinburgh,' which I have already quoted; his paper on 'The Effect of the Antiseptic System of Treatment on the Salubrity of a Surgical Hospital;' and the article in the 'British Medical Journal' of January 14, 1871.

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[1] 'Introductory Lecture before the University of Edinburgh.'

If, instead of using carbolic acid spray, he could surround his wounds with properly filtered air, the result would, he contends, be the same. In a room where the germs not only float but cling to clothes and walls, this would be difficult, if not impossible. But surgery is acquainted with a class of wounds in which the blood is freely mixed with air that has passed through the lungs, and it is a most remarkable fact that such air does not produce putrefaction. Professor Lister, as far as I know, was the first to give a philosophical interpretation of this fact, which he describes and comments upon thus:

> I have explained to my own mind the remarkable fact that in simple fracture of the ribs, if the lung be punctured by a fragment, the blood effused into the pleural cavity, though

> freely mixed with air, undergoes no decomposition. The air is sometimes pumped into the pleural cavity in such abundance that, making its way through the wound in the pleura costalis, it inflates the cellular tissue of the whole body. Yet this occasions no alarm to the surgeon (although if the blood in the pleura were to putrefy, it would infallibly occasion dangerous suppurative pleurisy). Why air introduced into the pleural cavity through a wounded lung, should have such wholly different effects from that entering directly through a wound in the chest, was to me a complete mystery until I heard of the germ theory of putrefaction, when it at once occurred to me that it was only natural that air should be filtered of germs by the air-passages, one of whose offices is to arrest inhaled particles of dust, and prevent them from entering the air-cells.

I shall have occasion to refer to this remarkable hypothesis farther on.

The advocates of the germ theory, both of putrefaction and epidemic disease, hold that both arise, not from the air, but from something contained in the air. They hold, moreover, that this 'something' is not a vapour nor a gas, nor indeed a molecule of any kind, but a *particle*.[1] The term 'particulate' has been used in the Reports of the Medical Department of the Privy Council to describe this supposed constitution of contagious matter; and Dr. Sanderson's experiments render it in the highest degree probable, if they do not actually demonstrate, that the virus of small-pox is 'particulate.' Definite knowledge upon this point is of exceeding importance, because in the treatment of *particles* methods are available which it would be futile to apply to *molecules*.

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[1] As regards size, there is probably no sharp line of division between molecules and particles; the one gradually shades into the other. But the distinction that I would draw is this: the atom or the molecule, if free, is always part of a gas, the particle is never so. A particle is a bit of liquid id matter, formed by the aggregation of atoms or molecules.

Application of Luminous Beams to these Researches.

My own interference with this great question, while sanctioned by eminent names, has been also an object of varied and ingenious attack. On this point I will only say that when angry feeling escapes from behind the intellect, where it may be useful as an urging force, and places itself athwart the intellect, it is liable to produce all manner of delusions. Thus my censors, for the most part, have levelled their remarks against positions which were never assumed, and against claims which were never made. The simple history of the matter is this: During the autumn of 1868 I was much occupied with the observations referred to at the beginning of this discourse. For fifteen years it had been my habit to make use of floating dust to reveal the paths of luminous beams through the air; but until 1868 I did not intentionally reverse the process, and employ a luminous beam to reveal and examine the dust. In a paper presented to the Royal Society in December, 1869, the observations which induced me to give more special attention to the question of spontaneous generation, and the germ theory of epidemic disease, are thus described:

The Floating Matter of the Air.

Prior to the discovery of the foregoing action (the chemical action of light upon vapours, Fragment IV.), and also during the experiments just referred to, the nature of my work compelled me to aim at obtaining experimental tubes absolutely clean upon the surface, and absolutely free within from suspended matter. Neither condition is, however, easily attained.

For however well the tubes might be washed and polished, and however bright and pure they might appear in ordinary daylight, the electric beam infallibly revealed signs and tokens of dirt. The air was always present, and it was sure to deposit some impurity. All chemical processes, not conducted in a vacuum, are open to this disturbance. When the experimental tube was exhausted, it exhibited no trace of floating matter, but on admitting the air through the U-tubes (containing caustic potash and sulphuric acid), a *dust-cone* more or less distinct was always revealed by the powerfully condensed electric beam.

The floating motes resembled minute particles of liquid which had been carried mechanically from the U-tubes into the experimental tube. Precautions were therefore taken to prevent any such transfer. They produced little or no mitigation. I did not imagine, at the time, that the dust of the external air could find such free passage through the caustic potash and sulphuric acid. This, however, was the case; the motes really came from without. They also passed with freedom through a variety of ethers and alcohols. In fact, it requires long-continued action on the part of an acid first to *wet* the motes and afterwards to destroy them. By carefully passing the air through the flame of a spirit-lamp, or through a platinum tube heated to bright redness, the floating matter was sensibly destroyed. It was therefore combustible, in other words, *organic*, matter. I tried to intercept it by a large respirator of cotton-wool. Close pressure was necessary to render the wool effective. A plug of the wool, rammed pretty tightly into the tube through which the air passed, was finally found competent to hold back the motes. They appeared from time to time afterwards, and gave me much trouble; but they were invariably traced in the end to some defect in the purifying apparatus—to some crack or flaw in the sealing-wax employed to render the tubes air-tight. Thus through proper care, but not without a great deal of searching out of disturbances, the experimental tube, even when filled with air or vapour, contains nothing competent to scatter the light. The space within it has the aspect of an absolute vacuum.

An experimental tube in this condition I call *optically empty*.

The simple apparatus employed in these experiments will be at once understood by reference to the figure on page 154. S S′ is the glass experimental tube, which has varied in length from 1 to 5 feet, and which may be from 2 to 3 inches in diameter. From the end S, the pipe $p\ p'$ passes to an air-pump. Connected with the other end S′ we have the flask F, containing the liquid whose vapour is to be examined; then follows a U-tube, T, filled with fragments of clean glass, wetted with sulphuric acid; then a second U-tube, T′, containing fragments of marble, wetted with caustic potash; and finally a narrow straight tube *t t′*, containing a tolerably tightly fitting plug of cotton-wool. To save the air-pump gauge from the attack of such vapours as act on mercury, as also to facilitate observation, a separate barometer tube was employed.

Through the cork which stops the flask F two glass tubes, *a* and *b*, pass air-tight. The tube *a* ends immediately under the cork; the tube *b*, on the contrary, descends to the bottom of the flask and dips into the liquid. The end of the tube *b* is drawn out so as to render very small the orifice through which the air escapes into the liquid.

The experimental tube S S′ being exhausted, a cock at the end S′ is turned carefully on. The air passes slowly through the cotton-wool, the caustic potash, and the sulphuric acid in succession. Thus purified, it enters the flask F and bubbles through the liquid. Charged with vapour, it finally passes into the experimental tube, where it is submitted to examination. The electric lamp L placed at the end of the experimental tube furnishes the necessary beam.

The facts here forced upon my attention had a bearing too evident to be overlooked. The inability of air which had been filtered through cotton-wool to generate animalcular life, had been demonstrated by Schroeder and Pasteur: here, the cause of its impotence was rendered evident to the eye. The experiment proved that no sensible amount of light was scattered by the *molecules* of the air; that the scattered light always arose from suspended *particles*; and the fact that the removal of these abolished simultaneously the power of scattering light and of originating life, obviously detached the life-originating power from the air, and fixed it on something suspended in the air. Gases of all kinds passed with freedom through the plug of cotton-wool; hence the thing whose

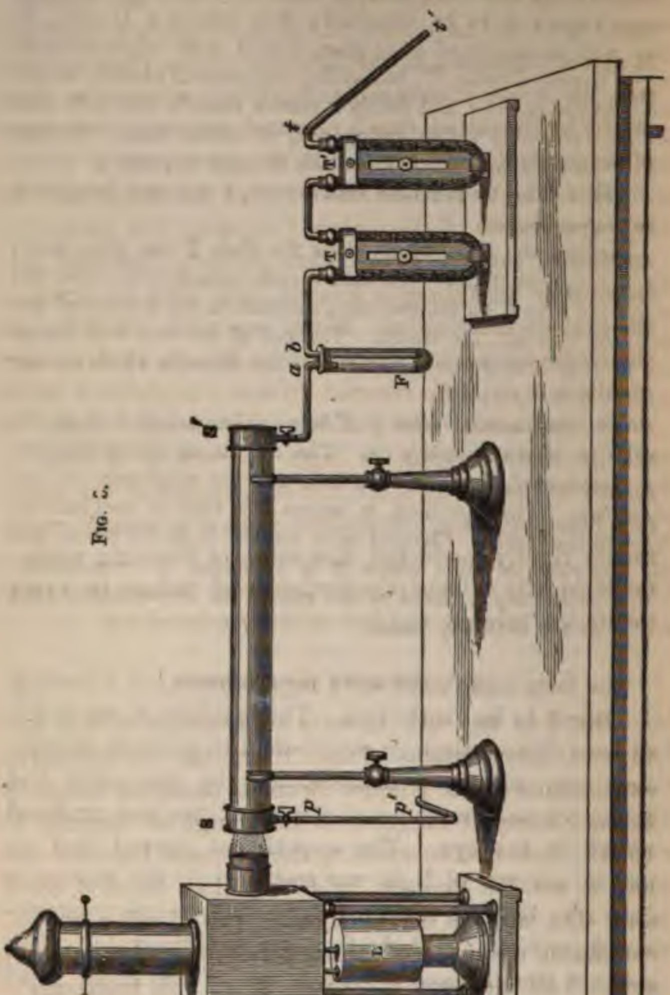

FIG. 2.

removal by the cotton-wool rendered the gas impotent, could not itself have been matter in the gaseous condition. It at once occurred to me that the retina, protected as it was, in these experiments, from all extraneous light, might be converted into a new and powerful instrument of demonstration in relation to the germ theory.

But the observations also revealed the danger incurred in experiments of this nature; showing that without an amount of care far beyond that hitherto bestowed upon them, such experiments left the door open to errors of the gravest description. It was especially manifest that the chemical method employed by Schultz in his experiments, and so often resorted to since, might lead to the most erroneous consequences; that neither acids nor alkalies had the power of rapid destruction hitherto ascribed to them. In short, the employment of the luminous beam rendered evident the cause of success in experiments rigidly conducted like those of Pasteur; while it made equally evident the certainty of failure in experiments less severely and less skilfully carried out.

Dr. Bennett's Experiments.

But I do not wish to leave an assertion of this kind without illustration. Take, then, the well-conceived experiments of Dr. Hughes Bennett, described before the Royal Society of Surgeons in Edinburgh on January 17, 1868.[1] Into flasks containing decoctions of liquorice-root, hay, or tea, Dr. Bennett, by an ingenious method, forced air. The air was driven through two U-tubes, the one containing a solution of caustic potash, the other sulphuric acid. 'All the bent tubes were filled with fragments of pumice-stone to break up the air, so as to prevent the possibility of any germs passing through in the centre of bubbles.' The air also passed through a Liebig's bulb containing sulphuric acid, and also through a bulb containing gun-cotton.

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[1] 'British Medical Journal,' 13, pt. ii. 1868.

It was only natural for Dr. Bennett to believe that his 'bent tubes' entirely cut off the germs. Previous to the observations just referred to, I also believed in their efficacy. But these observations destroy any such notion. The gun-cotton, moreover, will fail to arrest the whole of the floating matter unless it is tightly packed, and there is no indication in Dr. Bennett's memoir that it was so packed. On the whole, I should infer, from the mere inspection of Dr. Bennett's apparatus, the very results which he has described—a retardation of the development of life, a total absence of it in some cases, and its presence in others.

In his first series of experiments, eight flasks were fed with his sifted air, and five with common air. In ten or twelve days all the five had fungi in them; whilst it required from four to nine months to develop fungi in the others. In one of the eight, moreover, even after this interval no fungi appeared. In a second series of experiments there was a similar exception. In a third series the cork stoppers used in the first and second series were abandoned, and glass stoppers employed. Flasks containing decoctions of tea, beef, and hay were filled with common air, and other flasks with sifted air. In every one of the former fungi appeared and in not one of the latter. These experiments simply ruin the doctrine that Dr. Bennett finally espouses.

In all these negative cases, the prepared air was forced into the infusion when it was boiling hot. Dr. Bennett made a fourth series of experiments, in which, previous to forcing in the air, he permitted the flasks to cool. Into four bottles thus treated he forced prepared air, and after a time found fungi in all of them. What is his conclusion? Not that the boiling hot liquid, employed in his first experiments, had destroyed such germs as had run the gauntlet of his apparatus; but that air which, previous to being sealed up, had been exposed to a temperature of 212°, *is too rare to support life!* This conclusion is so remarkable that it ought to be stated in Dr. Bennett's own words. 'It may be easily conceived that air subjected to a boiling temperature is so expanded as scarcely to merit the name of air, and that it is more or less unfit for the purpose of sustaining animal or vegetable life.'

Now numerical data are attainable here, and as a matter of fact I live and flourish for a considerable portion of each year in a medium of less density than that which Dr. Bennett describes as scarcely meriting the name of air. The inhabitants of the higher Alpine châlets, with their flocks and herds, and the grasses which support these, do the same; while the chamois rears its kids in air rarer still. Insect life, moreover, is sometimes exhibited with monstrous prodigality at Alpine heights.

In a fifth series of experiments sixteen bottles were filled with infusions. Into four of them, while cold, ordinary unheated and unsifted air was pumped. In these four bottles fungi were developed. Into four other bottles, containing a boiling infusion, ordinary air was also pumped —no fungi were here developed. Into four other bottles containing an infusion which had been boiled and permitted to cool, sifted air was pumped—no fungi were developed. Finally, into four bottles containing a boiling infusion sifted air was pumped—no fungi were developed. Only, therefore, in the four cases where the infusions were cold infusions, and the air ordinary air, did fungi appear.

Dr. Bennett does not draw from his experiments the conclusion to which they so obviously point. On them, on the contrary, he founds a defence of the doctrine of spontaneous generation, and a general theory of *spontaneous development.* So strongly was he impressed with the idea that the germs could not possibly pass through his potash and sulphuric acid tubes, that the appearance of fungi, even in a small minority of cases, where the air had been sent through these tubes, was to him conclusive evidence of the spontaneous origin of such fungi. And he accounts for the absence of life in many of his experiments by an hypothesis which will not bear a moment's examination. But, knowing that organic particles may pass unscathed through alkalies and acids, the results of Dr. Bennett are precisely what ought under the circumstances to be expected. Indeed, their harmony with the conditions now revealed is a proof of the honesty and accuracy with which they were executed.

The caution exercised by Pasteur both in the execution of his experiments, and in the reasoning based upon them, is perfectly evident to those who, through the practice of severe experimental enquiry, have rendered themselves competent to judge of good experimental work. He found germs in the mercury used to isolate his air. He was never sure that they did not cling to the instruments he employed, or to his own person. Thus when he opened his hermetically sealed flasks upon the Mer de Glace, he had his eye upon the file used to detach the drawn-out necks of his bottles; and he was careful to stand to leeward when each flask was opened. Using these precautions, he found the glacier air incompetent, in nineteen cases out of twenty, to generate life; while similar flasks, opened amid the vegetation of the lowlands, were soon crowded with living things. M. Pouchet repeated Pasteur's experiments in the Pyrenees, adopting the precaution of holding his flasks above his head, and obtaining a different result. Now great care would be needed to render this procedure a real precaution. The luminous beam at once shows us its possible effect. Let smoking brown paper be placed at the open mouth of a glass shade, so that the smoke shall ascend and fill the shade. A beam sent through the shade forms a bright track through the smoke. When the closed fist is placed underneath the shade, a vertical wind of surprising violence, considering the small elevation of temperature, rises from the hand, displacing by comparatively dark air the illuminated smoke. Unless special care were taken such a wind would rise from M. Pouchet's body as he held his flasks above his head, and thus the precaution of Pasteur, of not coming between the wind and the flask, would be annulled.

Let me now direct attention to another result of Pasteur, the cause and significance of which are at once revealed by the luminous beam. He prepared twenty-one flasks, each containing a decoction of yeast, filtered and clear. He boiled the decoction so as to destroy whatever germs it might contain, and, while the space above the liquid was filled with pure steam, he sealed his flasks with a blow-pipe. He opened ten of them in the deep, damp caves of the Paris Observatory, and eleven of them in the courtyard of the establishment. Of the former, one only showed signs of life subsequently. In nine out of the ten flasks no organisms of any kind were developed. In all the others organisms speedily appeared.

Now here is an experiment conducted in Paris, on which we can throw obvious light in London. Causing our luminous beam to pass through a large flask filled with the air of this room, and charged with its germs and its dust, the beam is seen crossing the flask from side to side. But here is another similar flask, which cuts a clear gap out of the beam. It is filled with *unfiltered* air, and still no trace of the beam is visible. Why? By pure accident I stumbled on this flask in our apparatus room, where it had remained quiet for some time. Acting upon this obvious suggestion I set aside three other flasks, filled, in the first instance, with mote-filled air. They are now optically empty. Our former experiments proved that the life-producing particles attach themselves to the fibres of cotton-wool. In the present experiment the motes have been brought by gentle air-currents, established by slight differences of temperature within our closed vessels, into contact with the interior surface, to which they adhere. The air of these flasks has deposited its dust, germs and all, and is practically free from suspended matter.

I had a chamber erected, the lower half of which is of wood, its upper half being enclosed by four glazed window-frames. It tapers to a truncated cone at the top It measures in plan 3 ft. by 2 ft. 6 in., and its height is 5 ft. 10 in. On February 6 it was closed, every crevice that could admit dust, or cause displacement of the air, being carefully pasted over with paper. The electric beam at first revealed the dust within the chamber as it did in the air of the laboratory. The chamber was examined almost daily; a perceptible diminution of the floating matter being noticed as time advanced. At the end of a week the chamber was optically empty, exhibiting no trace of matter competent to scatter the light. Such must have been the case in the stagnant caves of the Paris Observatory. Were our electric beam sent through the air of these caves its track would be invisible; thus showing the indissoluble association of the scattering of light by air and its power to generate life.

I will now turn to what seems to me a more interesting application of the luminous beam than any hitherto described. My reference to Professor Lister's interpretation of the fact, that air which has passed through the lungs cannot produce putrefaction, is fresh in your memories. 'Why air,' said he, 'introduced into the pleural cavity, through a wounded lung, should have such wholly different effects from that entering through a permanently open wound, penetrating from without, was to me a complete mystery, till I heard of the germ theory of putrefaction, when it at once occurred to me that it was only natural that the air should be filtered of germs by the air-passages, one of whose offices is to arrest inhaled particles of dust, and prevent them from entering the air-cells.'

Here is a surmise which bears the stamp of genius, but which needs verification. If, for the words 'it is only natural' we were authorised to write 'it is perfectly certain,' the demonstration would be complete. Such demonstration is furnished by experiments with a beam of light. One evening, towards the close of 1869, while pouring various pure gases across the dusty track of a luminous beam, the thought occurred to me of using my breath instead of the gases. I then noticed, for the first time, the extraordinary darkness produced by the expired air, *towards the end of the expiration.* Permit me to repeat the experiment in your presence. I fill my lungs with ordinary air and breathe through a glass tube across the beam. The condensation of the aqueous vapour of the breath is shown by the formation of a luminous white cloud of delicate texture. We abolish this cloud by drying the breath previous to its entering the beam; or, still more simply, by warming the glass tube. The luminous track of the beam is for a time uninterrupted by the breath, because the dust returning from the lungs makes good, in great part, the particles displaced. After a time, however, an obscure disk appears in the beam, the darkness of which increases, until finally, towards the end of the expiration, the beam is, as it were, pierced by an intensely black hole, in which no particles whatever can be discerned. The deeper air of the lungs is thus proved to be absolutely free from suspended matter. It is therefore in the precise condition required by Professor Lister's explanation. This experiment may be repeated any number of times with the *same result.* I think it must be regarded as a crowning piece of evidence both of the correctness of Professor Lister's views and of the impotence, as regards vital development, of optically pure air.[1]

Application of Luminous Beams to Water.

The method of examination here pursued is also applicable to water. It is in some sense complementary to that of the microscope, and may, I think, materially aid enquiries conducted with that instrument. In microscopic examination attention is directed to a small portion of the liquid, and the aim is to detect the individual suspended particles. By the present method a large portion of the liquid is illuminated, its general condition being revealed, by the scattered light. Care is taken to defend the eye from the access of all other light, and, thus defended, it becomes an organ of inconceivable delicacy. Indeed, an amount of impurity so infinitesimal as to be scarcely expressible in numbers, and the individual particles of which are so small as wholly to elude the microscope, may, when examined by the method alluded to, produce not only sensible, but striking, effects upon the eye.

We will apply the method, in the first place, to an experiment of M. Pouchet intended to prove conclusively that animalcular life is developed in cases where no antecedent germs could possibly exist. He produced water from the combustion of hydrogen in air, justly arguing that no germ could survive the heat of a hydrogen flame. But he overlooked the fact that his aqueous vapour was condensed in the air, and was allowed as water to trickle through the air. Indeed the experiment is one of a number by which workers like M. Pouchet are differentiated from workers like Pasteur. I will show you some water, produced by allowing a hydrogen flame to play upon a polished silver condenser, formed by the bottom of a silver basin, containing ice. The collected liquid is pellucid in the common light; but in the condensed electric beam it is seen to be laden with particles, so thick-strewn and minute as to produce a continuous luminous cone. In passing through the air the water loaded itself with this matter; and the deportment of such water could obviously have no influence in deciding this great question.

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[1] Dr. Burdon Sanderson draws attention to the important observation of Brauell, which shows that the contagium of a pregnant animal, suffering from splenic fever, is not found in the blood of the fœtus; the placental *apparatus acting* as a filter, and holding back the infective particles.

We are invaded with dirt not only in the air we breathe, but in the water we drink. To prove this I take the bottle of water intended to quench your lecturer's thirst; which, in the track of the beam, simply reveals itself as dirty water. And this water is no worse than the other London waters. Thanks to the kindness of Professor Frankland, I have been furnished with specimens of the water of eight London companies. They are all laden with impurities mechanically suspended. But you will ask whether filtering will not remove the suspended matter? The grosser matter, undoubtedly, but not the more finely divided matter. Water may be passed any number of times through bibulous paper, it will continue laden with fine matter. Water passed through the charcoal filter of Lipscomb's, or through the filters of the Silicated Carbon Company, has its grosser matter removed, but it is thick with fine matter. Nine-tenths of the light scattered by these suspended particles is perfectly polarised in a direction at right angles to the beam, and this release of the particles from the ordinary law of polarisation is a demonstration of their smallness. I should say by far the greater number of the particles concerned in this scattering are wholly beyond the range of the microscope. and no ordinary filter can intercept such particles. It is next to impossible, by artificial means, to produce a pure water. Mr. Hartley, for example, some time ago distilled water while it was surrounded by hydrogen, but the water was not free from floating matter. It is so hard to be clean in the midst of dirt. In water from the Lake of Geneva, which has remained long without being stirred, we have an approach to the pure liquid. I have a bottle of it here, which was carefully filled for me by my distinguished friend Soret. The track of the beam through it is of a delicate sky-blue; there is scarcely a trace of grosser matter.

The purest water that I have seen—probably the purest which has been seen hitherto—has been obtained from the fusion of selected specimens of ice. But extraordinary precautions are required to obtain this degree of purity. The following apparatus has been devised and constructed by my assistant for this purpose: Through the plate of an air-pump passes the shank of a large funnel, attached to which below the plate is a clean glass bulb. In the funnel is placed a block of the most transparent ice, and over the funnel a glass receiver. This is first exhausted and refilled several times with air, filtered by its passage through cotton-wool, the ice being thus surrounded by pure moteless air. But the ice has previously been in contact with mote-filled air; it is therefore necessary to let it wash its own surface, and also to wash the bulb which is to receive the water of liquefaction. The ice is permitted to melt, the bulb is filled and emptied several times, until finally the large block dwindles to a small one. We may be sure that all impurity has been thus removed from the surface of the ice. The water obtained in this way is the purest hitherto obtained. Still I should hesitate to call it absolutely pure. When condensed light is sent through it, the track of the beam is not invisible, but of the most exquisitely delicate blue. This blue is purer than that of the sky, so that the matter which produces it must be finer than that of the sky. It may be, and indeed has been, contended that this blue is scattered by the very molecules of the water, and not by matter suspended in the water. But when we remember that this perfection of blue is approached gradually through stages of less perfect blue; and when we consider that a blue in all respects similar is demonstrably obtainable from particles mechanically suspended, we should hesitate, I think, to conclude that we have arrived here at the last stage of purification. The evidence, I think, points distinctly to the conclusion that could we push the process of purification still farther, even this last delicate trace of blue would disappear.

Chalk-water. Clark's Softening Process.

But is it not possible to match the water of the Lake of Geneva here in England? Undoubtedly it is. We have in England a kind of rock which constitutes at once an exceedingly clean recipient and a natural filter, and from which we can obtain water extremely free from mechanical impurities. I refer to the chalk formation, in which large quantities of water are held in store. Our chalk hills are in most cases covered with thin layers of soil, and with very scanty vegetation. Neither opposes much obstacle to the entry of the rain into the chalk, where any organic impurity which the water may carry in is soon oxidised and rendered harmless. Those who have scampered like myself over the downs of Hants and Wilts will remember the scarcity of water in these regions. In fact, the rainfall, instead of washing the surface and collecting in streams, sinks into the fissured chalk and percolates through it. When this formation is suitably tapped, we obtain water of exceeding briskness and purity. A large glass globe, filled with the water of a well near Tring shows itself to be wonderfully free from mechanical impurity. Indeed, it stands to reason that water wholly withdrawn from surface contamination, and percolating through so clean a substance, should be pure. It has been a subject much debated, whether the supply of excellent water which the chalk holds in store could not be rendered available for London. Many of the most eminent engineers and chemists have ardently recommended this source, and have sought to show, not only that its purity is unrivalled, but that its quantity is practically inexhaustible. Data sufficient to test this are now, I believe, in existence; the number of wells sunk in the chalk being so considerable, and the quantity of water which they yield so well known.

But this water, so admirable as regards freedom from mechanical impurity, labours under the disadvantage of being rendered very hard by the carbonate of lime which it holds in solution. The chalk-water in the neighbourhood of Watford contains about seventeen grains of carbonate of lime per gallon. This, in the old terminology, used to be called seventeen degrees of hardness. Now this hard water is bad for tea, bad for washing; and it furs our boilers, because the lime held in solution is precipitated by boiling. If the water be used cold, its hardness must be neutralised at the expense of soap, before it will give a lather. These are serious objections to the use of chalk-water in London. But they are successfully met by the demonstration that such water can be softened inexpensively, and on a grand scale. I had long known the method of softening water called Clark's process, but not until recently, under the guidance of Mr. Homersham, did I see proof of its larger applications. The chalk-water is softened for the supply of the city of Canterbury; and at the Chiltern Hills it is softened for the supply of Tring and Aylesbury. Caterham also enjoys the luxury.

I have visited all these places, and made myself acquainted with the works. At Canterbury there are three reservoirs covered in and protected, by a concrete roof and layers of pebbles, both from the summer's heat and the winter's cold. Each reservoir can hold 120,000 gallons of water. Adjacent to these reservoirs are others containing pure slaked lime—the so-called 'cream of lime.' These being filled with water, the lime and water are thoroughly mixed by air forced in by an engine through apertures in the bottom of the reservoir. The water soon dissolves all the lime it is capable of dissolving. The mechanically suspended lime is then allowed to subside to the bottom, leaving a perfectly transparent lime-water behind.

The softening process is this: Into one of the empty reservoirs is introduced a certain quantity of the clear lime-water, and after this about nine times the quantity of the chalk-water. The transparency immediately disappears—the mixture of the two clear liquids becoming thickly turbid, through the precipitation of carbonate of lime. The precipitate is permitted to subside. It is crystalline and heavy, and in about twelve hours a layer of pure white carbonate of lime is formed at the bottom of the reservoir, with a water of extraordinary beauty and purity overhead. A few days ago I pitched some halfpence into a reservoir sixteen feet deep at the Chiltern Hills. This depth hardly dimmed the coin. Had I cast in a pin, it could have been seen at the bottom. By this process of softening, the water is reduced from about seventeen degrees of hardness, to three degrees of hardness. It yields a lather immediately. Its temperature is constant throughout the year. In the hottest summer it is cool, its temperature being twenty degrees above the freezing point; and it does not freeze in winter if conveyed in proper pipes. The reservoirs are covered; a leaf cannot blow into them, and no surface contamination can reach the water. It passes direct from the main into the house tap; no cisterns are employed, and the supply is always fresh and pure. This is the kind of water which is supplied to the fortunate people of Tring, Caterham, and Canterbury.

The foregoing article, as far as it relates to the theory which ascribes epidemic disease to the development of low parasitic life within the human life, was embodied in a discourse delivered before the Royal Institution in January 1870. In June 1871, after a brief reference to the polarisation of light by cloudy matter, I ventured to recur to the subject in these terms: What is the practical uses of these curiosities? If we exclude the interest attached to the observation of new facts, and the enhancement of that interest through the knowledge that facts often become the exponents of laws, these curiosities are in themselves worth little. They will not enable us to add to our stock of food, or drink, or clothes, or jewellery. But though thus shorn of all usefulness in themselves, they may, by carrying thought into places which it would not otherwise have entered, become the antecedents of practical consequences. In looking, for example, at our illuminated dust, we may ask ourselves what it is. How does it act, not upon a beam of light, but upon our own organisations? The question then assumes a practical character. We find on examination that this dust is organic matter—in part living, in part dead. There are among it particles of ground straw, torn rags, smoke, the pollen of flowers, the spores of fungi, and the germs of other things. But what have they to do with the animal economy? Let me give you an illustration to which my attention has been lately drawn by Mr. George Henry Lewes, who writes to me thus:

'I wish to direct your attention to the experiments of Von Recklingshausen should you happen not to know them. They are striking confirmations of what you say of dust and disease. Last spring, when I was at his laboratory in Würzburg, I examined with him blood that had been three weeks, a month, and five weeks, out of the body, preserved in little porcelain cups under glass shades. This blood was living and growing. Not only were the Amœba-like movements of the white corpuscles present, but there were abundant evidences of the growth and development of the corpuscles. I also saw a frog's heart still pulsating which had been removed from the body (I forget how many days, but certainly more than a week). There were other examples of the same persistent vitality, or absence of putrefaction. Von Recklingshausen did not attribute this to the absence of germs—germs were not mentioned by him; but when I asked him how he represented the thing to himself, he said the whole mystery of his operation consisted in keeping the blood *free from dirt*. The instruments employed were raised to a red heat just before use; the thread was silver thread and was similarly treated; and the porcelain cups, though not kept free from air, were kept free from currents. He said he often had failures, and these he attributed to particles of dust having escaped his precautions.'

Professor Lister, who has founded upon the removal or destruction of this 'dirt' great and numerous improvements in surgery, tells us the effect of its introduction into the blood of wounds. He informs us what would happen with the extracted blood should the dust get at it. The blood would putrefy and become fetid; and when you examine more closely what putrefaction means, you find the putrefying substance swarming with organic life, the germs of which have been derived from the air.

We are now assuredly in the midst of practical matters; and with your permission I will refer once more to a question which has recently occupied a good deal of public attention. As regards the lowest forms of life, the world is divided, and has for a long time been divided, into two parties, the one affirming that we have only to submit absolutely dead matter to certain physical conditions, to envolve from it living things; the other (without wishing to set bounds to the power of matter) affirming that, *in our day*, life has never been found to rise independently of pre-existing life. I belong to the party which claims life as a derivative of life. The question has two factors—the evidence, and the mind that judges of the evidence; and it may be purely a mental set or bias on my part that causes me throughout this long discussion, to see, on the one side, dubious facts and defective logic, and on the other side firm reasoning and a knowledge of what rigid experimental enquiry demands. But, judged of practically, what, again, has the question of Spontaneous Generation to do with us? Let us see. There are numerous diseases of men and animals that are demonstrably the products of parasitic life, and such diseases may take the most terrible epidemic forms, as in the case of the silkworms of France in our day. Now it is in the highest degree important to know whether the parasites in question are spontaneously developed, or are wafted from without to those afflicted with the disease. The means of prevention, if not of cure, would be widely different in the two cases.

But this is not all. Besides these universally admitted cases, there is the broad theory, now broached and daily growing in strength and clearness—daily, indeed, gaining more and more of assent from the most successful workers and profound thinkers of the medical profession itself—

the theory, namely, that contagious disease, generally, is of this parasitic character. Had I any cause to regret having introduced this theory to your notice more than a year ago, that regret should now be expressed. I would certainly renounce in your presence whatever leaning towards the germ theory my words might then have betrayed. But since the time referred to I have heard or read nothing which shakes my conviction of the truth of the theory. Let me briefly state the grounds on which its supporters rely. From their respective viruses you may plant typhoid fever, scarlatina, or small-pox. What is the crop that arises from this husbandry? As surely as a thistle rises from a thistle seed, as surely as the fig comes from the fig, the grape from the grape, the thorn from the thorn, so surely does the typhoid virus increase and multiply into typhoid fever, the scarlatina virus into scarlatina, the small-pox virus into small-pox. What is the conclusion that suggests itself here? It is this: That the thing which we vaguely call a virus is to all intents and purposes a *seed*: that, excluding the notion of vitality, in the whole range of chemical science you cannot point to an action which illustrates this perfect parallelism with the phenomena of life—this demonstrated power of self-multiplication and reproduction. The germ theory alone accounts for the phenomena.

In cases of epidemic disease, it is not on bad air or foul drains that the attention of the physician of the future will primarily be fixed, but upon disease germs, which no bad air or foul drains can create, but which may be pushed by foul air into virulent energy of reproduction. You may think I am treading on dangerous ground, that I am putting forth views that may interfere with salutary practice. No such thing. If you wish to learn the impotence of medical practice in dealing with contagious diseases, you have only to refer to a recent Harveian oration by

Dr. Gull. Such diseases defy the physician. They must run their course, and the utmost that can be done for them is careful nursing. And this, though I do not specially insist upon it, would favour the idea of their vital origin. For if the seeds of contagious disease be themselves living things, it may be difficult to destroy either them or their progeny, without involving their living habitat in the same destruction.

It has been said, and it is sure to be repeated, that I am quitting my own *métier*, in speaking of these things. Not so. I am dealing with a question on which minds accustomed to weigh the value of experimental evidence are alone competent to decide, and regarding which, in its present condition, minds so trained are as capable of forming an opinion as regarding the phenomena of magnetism or radiant heat. 'The germ theory of disease,' it has been said, 'appertains to the biologist and the physician.' Granted. But where is the biologist or physician, whose researches, in connection with this subject, could for one instant be compared to those of the chemist Pasteur? It is not the philosophic members of the medical profession who are dull to the reception of truth not originated within the pale of the profession itself. I cannot better conclude this portion of my story than by reading to you an extract from a letter addressed to me some time ago by Dr. William Budd, of Clifton, to whose insight and energy the town of Bristol owes so much in the way of sanitary improvement.

'As to the germ theory itself,' writes Dr. Budd, 'that is a matter on which I have long since made up my mind. From the day when I first began to think of these subjects, I had never had a doubt that the specific cause of contagious fevers must be living organisms.

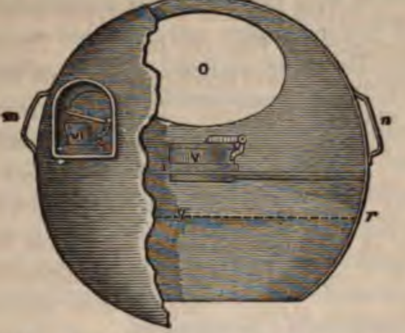
'It is impossible, in fact, to make any statement bearing upon the essence or distinctive characters of these fevers, without using terms which are of all others *the most distinctive of life.* Take up the writings of the most violent opponent of the germ theory, and, ten to one, you will find them full of such terms as "propagation," "self-propagation," "reproduction," "self-multiplication," and so on. Try as he may—if he has anything to say of those diseases which is characteristic of them—he cannot evade the use of these terms, or the exact equivalents to them. While perfectly applicable to living things, these terms express qualities which are not only inapplicable to common chemical agents, but, as far as I can see, actually inconceivable of them.'

Cotton-wool Respirator.

Once, then, established within the body, this evil form of life, if you will allow me to call it so, must run its course. Medicine as yet is powerless to arrest its progress, and the great point to be aimed at is to prevent its access to the body. It was with this thought in my mind that I ventured to recommend, more than a year ago, the use of cotton-wool respirators in infectious places. I would here repeat my belief in their efficacy if properly constructed. But I do not wish to prejudice the use of these respirators, by connecting them indissolubly with the germ theory. There are too many trades in England where life is shortened and rendered miserable by the introduction of matters into the lungs which might be kept out of them. Dr. Greenhow has shown the stony grit deposited in the lungs of stonecutters. The black lungs of colliers is another case in point. In fact, a hundred obvious cases might be cited, and others that are not obvious might be added to them. We should not, for example, think that printing implied labours where the use of cotton-wool respirators might come into play; but the fact is that the dust arising from the sorting of the type is very destructive of health. I went some time ago into a manufactory in one of our large towns, where iron vessels are enamelled by coating them with a mineral powder, and subjecting them to a heat sufficient to fuse the powder. The organisation of the establishment was excellent, and one thing only was needed to make it faultless. In a large room a number of women were engaged covering the vessels. The air was laden with the fine dust, and their faces appeared as white and bloodless as the powder with which they worked. By the use of cotton-wool respirators these women might be caused to breathe air as free from suspended matter as that of the open street. Over a year ago a Lancashire seedsman wrote to me, stating that during the seed season his men suffered horribly from irritation and fever, so that many of them left his service. He asked for help, and I gave him my advice. At the conclusion of the season, this year, he wrote to inform me that he had folded a little cotton-wool in muslin, and tied it in front of the mouth; and that with this simple defence he had passed through the season in comfort, and without a single complaint from his men.

Against the use of such a respirator the obvious objection arises, that it becomes wet and heated by the breath. While I was casting about for a remedy for this a friend forwarded to me from Newcastle a form of respirator invented by Mr. Carrick, a hotel-keeper at Glasgow, which, by a slight modification, may be caused to meet the case perfectly. The respirator, with its back in part removed, is shown in fig. 4. Under the partition of wire-gauze *q r*, is a space intended by Mr. Carrick for 'medicated substances,' and which may be filled with cotton-wool The mouth is placed against the aperture O, which fits closely round the lips, and the filtered air enters the mouth through a light valve V, which is lifted by the act of inhalation. During exhalation this valve closes; the breath escapes by a second valve, v, into the open air.

Fig. 4.



The wool is thus kept dry and cool; the air in passing through it being filtered of everything it holds in suspension.

Fireman's Respirator.

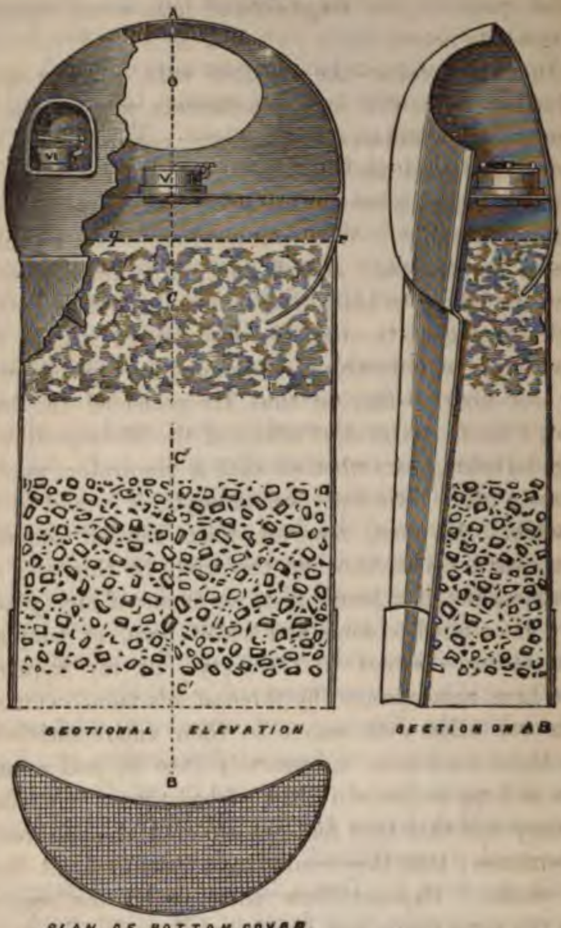
We have thus been led by our first unpractical experiments into a thicket of practical considerations. But another step is possible. Admiring, as I do, the bravery of our firemen, and hearing that smoke was a more serious enemy than flame itself, I thought of devising a fireman's respirator.

Our fire-escapes are each in charge of a single man, and it would be of obvious importance to place it in the power of each of those men to penetrate through the densest smoke, into the recesses of a house, and there to rescue those who would otherwise be suffocated or burnt. Cotton-wool, which so effectually arrested dust, was first tried; but, though found soothing in certain gentle kinds of smoke, it was no match for the pungent fumes of a resinous fire, which evolves a most abominable smoke. For the purpose of catching the atmospheric germs, M. Pouchet spread a film of glycerine on a plate of glass, urged air against the film, and examined the dust which stuck to it. The moistening of the cotton-wool with this substance was a decided improvement; still the respirator only enabled us to remain in dense smoke for three or four minutes, after which the irritation became unendurable. Reflection suggested that, in combustion so imperfect as the production of dense smoke implies, there must be numerous hydrocarbons produced, which, being in a state of vapour, would be very imperfectly arrested by the cotton-wool. These, in all probability, were the cause of the residual irritation; and if these could be removed, a practically perfect respirator might possibly be obtained.

I state the reasoning exactly as it occurred to my mind. Its result will be anticipated by many present. All bodies possess the power of condensing, in a greater or less degree, gases and vapours upon their surfaces, and when the condensing body is very porous, or in a fine state of division, the force of condensation may produce very remarkable effects. Thus, a clean piece of platinum-foil placed in a mixture of oxygen and hydrogen so squeezes the gases together as to cause them to combine; and if the experiment be made with care, the heat of combination may raise the platinum to bright redness. The promptness of this action is greatly augmented by reducing the platinum to a state of fine division. A pellet of 'spongy platinum,' for instance, plunged into a mixture of oxygen and hydrogen, causes the gases to explode instantly. In virtue of its extreme porosity, a similar power is possessed by charcoal. It is not strong enough to cause the oxygen and hydrogen to combine like the spongy platinum, but it so squeezes the more condensable vapours, and acts with such condensing power upon the oxygen of the air, as to bring both within the combining distance, thus enabling the oxygen to attack and destroy the vapours in the pores of the charcoal. In this way, effluvia of all kinds may be virtually burnt up; and this is the principle of the excellent charcoal respirators invented by Dr. Stenhouse. Armed with one of these, you may go into the foulest-smelling places without having your nose offended.

But, while powerful to arrest vapours, the charcoal respirator is ineffectual as regards smoke. The smoke-particles get freely through the respirator. With a number of such respirators, tested downstairs, from half a minute to a minute was the limit of endurance. This might be exceeded by Faraday's simple method of emptying the lungs completely, and then filling them before going into a smoky atmosphere. In fact, each solid smoke particle is itself a bit of charcoal, and carries on it, and in it, its little load of irritating vapour. It is this, far more than the particles of carbon themselves, that produces the irritation. Hence two causes of offence are to be removed: the carbon particles which convey the irritant by adhesion and condensation, and the free vapour which accompanies the particles. The moistened cotton-wool I knew would arrest the first; fragments of charcoal I hoped would stop the second. In the first fireman's respirator, Mr. Carrick's arrangement of two valves, the one for inhalation, the other for exhalation, are preserved. But the portion of it which holds the filtering and absorbent substances, is prolonged to a depth of four or five inches (see fig. 5). Under the partition of wire-gauze *q r* at the bottom of the space which fronts the mouth is placed a layer of cotton-wool, c, moistened with glycerine; then a thin layer of dry wool, c′; then a layer of charcoal fragments; and finally a second thin layer of dry cotton-wool. The succession of the layers may be changed without prejudice to the action. A wire-gauze cover, shown in plan below fig. 5, keeps the substances from falling out of the respirator. A layer of caustic lime has been added for th absorption of carbonic acid; but in the densest smok

FIG. 5.



that we have hitherto employed, it has not been found n cessary, nor is it shown in the figure. In a flaming buil ing, indeed, the mixture of air with the smoke never permits the carbonic acid to become so dense as to be irrespirable; but in a place where the gas is present in undue quantity, the fragments of lime would materially mitigate its action.

In a small cellar-like chamber with a stone flooring and stone walls, the first experiments were made. We placed there furnaces containing resinous pine-wood, lighted the wood, and, placing over it a lid which prevented too brisk a circulation of the air, generated dense volumes of smoke. With our eyes protected by suitable glasses, my assistant and I have remained for half an hour and more in smoke so dense and pungent that a single inhalation, through the undefended mouth, would be perfectly unendurable. We might have prolonged our stay for hours. Having thus far perfected the instrument, I wrote to the chief officer of the Metropolitan Fire Brigade, asking him whether such a respirator would be of use to him. His reply was prompt; it would be most valuable. He had, however, made himself acquainted with every contrivance of the kind in this and other countries, and had found none of them of any practical use. He offered to come and test it here, or to place a room at my disposal in the City. At my request he came here, accompanied by three of his men. Our small room was filled with smoke to their entire satisfaction. The three men went successively into it, and remained there as long as Captain Shaw wished them. On coming out they said that they had not suffered the slightest inconvenience; that they could have remained all day in the smoke. Captain Shaw then tested the respirator with the same result, and he afterwards took great interest in the perfecting of the instrument.

Various ameliorations and improvements have recently been introduced into the smoke respirator. The hood of Captain Shaw has been improved upon by the simple and less expensive mouthpiece of Mr. Sinclair; and this, in its turn, has been simplified and improved by my assistant Mr. John Cottrell. The respirator is now in considerable demand, and it has already done good practical service. Care is, however, necessary in moistening the wool with glycerine. It must be carefully teazed, so that the individual fibres may be moistened, and *clots* must be avoided. I cannot recommend the layers of moistened flannel which, in some cases, have been used instead of cotton-wool: nothing equals the wool, when carefully treated.

An experiment made last year brought out very conspicuously the necessity of careful packing, and the enormous comparative power of resisting smoke irritation possessed by our firemen, and the able officer who commands them. Having heard from Captain Shaw that, in some recent very trying experiments, he had obtained the best effects from dry cotton-wool, and thinking that I could not have been mistaken in my first results, which proved the dry so much inferior to the moistened wool and its associated charcoal, I proposed to Captain Shaw to bring the matter to a test at his workshops in the City. He was good enough to accept my proposal, and thither I went on May 7, 1874. The smoke was generated in a confined space from wet straw, and it was certainly very diabolical. At this season of the year I am usually somewhat shorn of vigour, and therefore not in the best condition for severe experiments; still I wished to test the matter in my own person. With a respirator which had been in use some days previously, and which was not carefully packed, I followed a fireman into the smoke, he being provided with a dry-wool respirator. I was compelled to quit the place in about three minutes, while the fireman remained there for six or seven minutes.

I then tried his respirator upon myself, and found that with it I could not remain more than a minute in the smoke; in fact the first inhalation provoked coughing.

Thinking that Captain Shaw himself might have lungs more like mine than those of his fireman, I proposed that we should try the respirators together; but he informed me that his lungs were very strong. He was, however, good enough to accede to my request. Before entering the den a second time I repacked my respirator, with due care, and entered the smoke in company with Captain Shaw. I could hear him breathe long slow inhalations; his labour was certainly greater than mine, and after the lapse of seven minutes I heard him cough. In seven and a half minutes he had to quit the place, thus proving that his lungs were able to endure the irritation seven times as long as mine could bear it. I continued in the smoke, with hardly any discomfort, for sixteen minutes, and certainly could have remained in it much longer. The advantage arising from the glycerine was thus placed beyond question.

During this time I was in a condition to render very material assistance to a person in danger of suffocation.

Helmholtz on Hay Fever.

In my lecture on Dust and Disease in 1870, I referred to an experiment made by Helmholtz upon himself which strikingly connected hay fever with animalcular life. About a year ago I received from Professor Binz of Bonn a short, but important paper, embracing Helmholtz's account of his observation, to which Professor Binz has added some remarks of his own. The paper, being mainly intended for English medical men, was published in English, and though here and there its style might be amended, I think it better to publish it unaltered here.

From what I have observed (says Professor Binz) of recent English publications on the subject of hay fever, I am led to suppose that English authorities are inaccurately acquainted with the discovery of Professor Helmholtz, as far back as 1868, of the existence of uncommon low organisms in the nasal secretions in this complaint, and of the possibility of arresting their action by the local employment of quinine. I therefore purpose to republish the letter in which he originally announced these facts to myself, and to add some further observations on this topic. The letter is as follows:[1]—

'I have suffered, as well as I can remember, since the year 1847, from the peculiar catarrh called by the English "hay fever," the speciality of which consists in its attacking its victims regularly in the hay season (myself between May 20 and the end of June), that it ceases in the cooler weather, but on the other hand quickly reaches a great intensity if the patients expose themselves to heat and sunshine. An extraordinarily violent sneezing then sets in, and a strongly corrosive thin discharge, with which much epithelium is thrown off. This increases, after a few hours, to a painful inflammation of the mucous membrane and of the outside of the nose, and excites fever with severe headache and great depression, if the patient cannot withdraw himself from the heat and the sunshine. In a cool room, however, these symptoms vanish as quickly as they come on, and there then only remains for a few days a lessened discharge and soreness, as if caused by the loss of epithelium. I remark, by the way, that in all my other years I had very little tendency to catarrh or catching cold, while the hay fever has never failed during the twenty-one years of which I have spoken, and has never attacked me earlier or later in the year than the times named. The condition is extremely troublesome, and increases, if one is obliged to be much exposed to the sun, to an excessively severe malady.

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[1] Cf. Virchow's 'Archiv.' vol. xlvi. p. 100.

'The curious dependence of the disease on the season of the year suggested to me the thought that organisms might be the origin of the mischief. In examining the secretion I regularly found, in the last five years, certain vibrio-like bodies in it, which *at other times I could not observe* in my nasal secretion. . . . They are very small, and can only be recognised with the immersion-lens of a very good Hartnack's microscope. It is characteristic of the common isolated single joints that they contain four nuclei in a row, of which two pairs are more closely united. The length of the joints is 0·004 millimetre. Upon the warm objective-stage they move with moderate activity, partly in mere vibration, partly shooting backwards and forwards in the direction of their long axis; in lower temperatures they are very inactive. Occasionally one finds them arranged in rows upon each other, or in branching series. Observed some days in the moist chamber, they vegetated again, and appeared somewhat larger and more conspicuous than immediately after their excretion. It is to be noticed that only that kind of secretion contains them which is expelled by violent sneezings; that which drops slowly does not contain any. They stick tenaciously enough in the lower cavities and recesses of the nose.

'When I saw your first notice respecting the poisonous action of quinine upon infusoria, I determined at once to make an experiment with that substance, thinking that these vibrionic bodies, even if they did not cause the whole illness, still could render it much more unpleasant through their movements and the decompositions caused by them. For that reason I made a neutral solution of sulphate of quinine, which did not contain much of the salt (1·800), but still was effective enough, and caused moderate irritation on the mucous membrane of the nose. I then lay flat on my back, keeping my head very low, and poured with a pipette about four cubic centimetres into both nostrils. Then I turned my head about in order to let the liquid flow in all directions.

'The desired effect was obtained immediately, and remained for some hours; I could expose myself to the sun without fits of sneezing and the other disagreeable symptoms coming on. It was sufficient to repeat the treatment three times a day, even under the most unfavourable circumstances, in order to keep myself quite free.[1] There were then no such vibrios in the secretion. If I only go out in the evening, it suffices to inject the quinine once a day, just before going. After continuing this treatment for some days the symptoms disappear completely, but if I leave off they return till towards the end of June.

'My first experiments with quinine date from the summer of 1867; this year (1868) I began at once as soon as the first traces of the illness appeared, and I have thus been able to stop its development completely.

'I have hesitated as yet in publishing the matter, because I have found no other patient[2] on whom I could try the experiment. There is, it seems to me, no doubt, considering the extraordinary regularity in the recurrence and course of the illness, that quinine had here a most quick and decided effect. And this again makes my hypothesis very probable, that the vibrios, even if being no specific form but a very frequent one, are at least the cause of the rapid increase of the symptoms in warm air, as heat excites them to lively action.'

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[1] There is no foundation for the objection that syringing the nose could not cure the asthma which accompanies hay fever; for this asthma is only the reflex effect arising from the irritation of the nose.—*B.*

[2] Helmholtz, now Professor of Physics at the University of Berlin, is, although M.D., no medical practitioner.'—*B.*

I should be very glad if the above lines would induce medical men in England—the haunt of hay fever—to test the observation of Helmholtz. To most patients the application with the pipette may be too difficult or impossible; I have therefore already suggested the use of Weber's very simple but effective nose-douche. Also it will be advisable to apply the solution of quinine *tepid*. It can, further, not be repeated often enough that quinine is frequently adulterated, especially with cinchonia, the action of which is much less to be depended upon.

Dr. Frickhöfer, of Schwalbach, has communicated to me a second case in which hay fever was cured by local application of quinine.[1] Professor Busch, of Bonn, authorises me to say that he succeeded in two cases of 'catarrhus æstivus' by the same method: a third patient was obliged to abstain from the use of quinine, as it produced an unbearable irritation of the sensible nerves of the nose. In the autumn of 1872 Helmholtz told me that his fever was quite cured, and that in the meantime two other patients had, by his advice, tried this method, and with the same success.

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[1] Cf. Virchow's 'Archiv.' (1870), vol. li. p. 176.

VI.

VOYAGE TO ALGERIA TO OBSERVE THE ECLIPSE.

1870.

THE opening of the Eclipse Expedition was not propitious. Portsmouth, on December 5, 1870, was swathed by a fog, which was intensified by smoke, and traversed by a drizzle of fine rain. At six P.M. I was on board the 'Urgent.' On Tuesday morning the weather was too thick to permit of the ship's being swung and her compasses calibrated. The Admiral of the port, a man of very noble presence, came on board. Under his stimulus the energy which the weather had damped appeared to become more active, and soon after his departure we steamed down to Spithead. Here the fog had so far lightened as to enable the officers to swing the ship.

At three P.M. on Tuesday, December 6, we got away, gliding successively past Whitecliff Bay, Bembridge, Sandown, Shanklin, Ventnor, and St. Catherine's Lighthouse. On Wednesday morning we sighted the Isle of Ushant, on the French side of the Channel. The northern end of the island has been fretted by the waves into detached tower-like masses of rock of very remarkable appearance. In the Channel the sea was green, and opposite Ushant it was a brighter green. On Wednesday evening we committed ourselves to the Bay of Biscay. The roll of the Atlantic was full, but not violent. There had been scarcely a gleam of sunshine throughout the day, but the cloud-forms were fine, and their apparent solidity impressive. On Thursday morning the green of the sea was displaced by a deep indigo blue. The whole of Thursday we steamed across the bay. We had little blue sky, but the clouds were again grand and varied—cirrus, stratus, cumulus, and nimbus, we had them all. Dusky hair-like trails were sometimes dropped from the distant clouds to the sea. These were falling showers, and they sometimes occupied the whole horizon, while we steamed across the rainless circle which was thus surrounded. Sometimes we plunged into the rain, and once or twice, by slightly changing our course, avoided a heavy shower. From time to time perfect rainbows spanned the heavens from side to side. At times a bow would appear in fragments, showing the keystone of the arch midway in air, and its two buttresses on the horizon. In all cases the light of the bow could be quenched by a Nicol's prism, with its long diagonal tangent to the arc. Sometimes gleaming patches of the firmament were seen amid the clouds. When viewed in the proper direction, the gleam could be quenched .by a Nicol's prism, a dark aperture being thus opened into stellar space.

At sunset on Thursday the denser clouds were fiercely fringed, while through the lighter ones seemed to issue the glow of a conflagration. On Friday morning we sighted Cape Finisterre—the extreme end of the arc which sweeps from Ushant round the Bay of Biscay. Calm spaces of blue, in which floated quietly scraps of cumuli, were behind us, but in front of us was a horizon of portentous darkness. It continued thus threatening throughout the day. Towards evening the wind strengthened to a gale, and at dinner it was difficult to preserve the plates and dishes from destruction. Our thinned company hinted that the rolling had other consequences. It was very wild when we went to bed. I slumbered and slept but after some time was rendered anxiously conscious that my body had become a kind of projectile, with the ship's side for a target. I gripped the edge of my berth to save myself from being thrown out. Outside, I could hear somebody say that he had been thrown from his berth, and sent spinning to the other side of the saloon. The screw laboured violently amid the lurching; it incessantly quitted the water, and, twirling in the air, rattled against its bearings, and caused the ship to shudder from stem to stern. At times the waves struck us, not with the soft impact which might be expected from a liquid, but with the sudden solid shock of battering-rams. 'No man knows the force of water,' said one of the officers, 'until he has experienced a storm at sea.' These blows followed each other at quicker intervals, the screw rattling after each of them, until, finally, the delivery of a heavier stroke than ordinary seemed to reduce the saloon to chaos. Furniture crashed, glasses rang, and alarmed enquiries immediately followed. Amid the noises I heard one note of forced laughter; it sounded very ghastly. Men tramped through the saloon, and busy voices were heard aft, as if something there had gone wrong.

I rose, and not without difficulty got into my clothes. In the after-cabin, under the superintendence of the able and energetic navigating lieutenant, Mr. Brown, a group of blue-jackets were working at the tiller-ropes. These had become loose, and the helm refused to answer the wheel. High moral lessons might be gained on shipboard, by observing what steadfast adherence to an object can accomplish, and what large effects are heaped up by the addition of infinitesimals. The tiller-rope, as the blue-jackets strained in concert, seemed hardly to move; still it did move a little, until finally, by timing the pull to the lurching of the ship, the mastery of the rudder was obtained. I had previously gone on deck. Round the saloon-door were a few members of the eclipse party, who seemed in no mood for scientific observation. Nor did I; but I wished to see the storm. I climbed the steps to the poop, exchanged a word with Captain Toynbee, the only member of the party to be seen on the poop, and by his direction made towards a cleat not far from the wheel.[1] Round it I coiled my arms. With the exception of the men at the wheel, who stood as silent as corpses, I was alone.

I had seen grandeur elsewhere, but this was a new form of grandeur to me. The 'Urgent' is long and narrow, and during our expedition she lacked the steadying influence of sufficient ballast. She was for a time practically rudderless, and lay in the trough of the sea. I could see the long ridges, with some hundreds of feet between their crests, rolling upon the ship perfectly parallel to her sides. As they approached, they so grew upon the eye as to render the expression 'mountains high' intelligible. At all events, there was no mistaking their mechanical might, as they took the ship upon their shoulders, and swung her like a pendulum. The deck sloped sometimes at an angle which I estimated at over forty-five degrees; wanting my previous Alpine practice, I should have felt less confidence in my grip of the cleat. Here and there the long rollers were tossed by interference into heaps of greater height. The wind caught their crests, and scattered them over the sea, the whole surface of which was seething white. The aspect of the clouds was a fit accompaniment to the fury of the ocean. The moon was almost full—at times concealed, at times revealed, as the scud flew wildly over it. These things appealed to the eye, while the ear was filled by the groaning of the screw and the whistle and boom of the storm.

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[1] The cleat is a T-shaped mass of metal employed for the fastening of ropes.

Nor was the outward agitation the only object of interest to me. I was at once subject and object to myself, and watched with intense interest the workings of my own mind. The 'Urgent' is an elderly ship. She had been built, I was told, by a contracting firm for some foreign Government, and had been diverted from her first purpose when converted into a troop-ship. She had been for some time out of work, and I had heard that one of her boilers, at least, needed repair. Our scanty but excellent crew, moreover, did not belong to the 'Urgent,' but had been gathered from other ships. Our three lieutenants were also volunteers. All this passed swiftly through my mind as the steamer shook under the blows of the waves, and I thought that probably no one on board could say how much of this thumping and straining the 'Urgent' would be able to bear. This uncertainty caused me to look steadily at the worst, and I tried to strengthen myself in the face of it.

But at length the helm laid hold of the water, and the ship was got gradually round to face the waves. The rolling diminished, a certain amount of pitching taking its place. Our speed had fallen from eleven knots to two. I went again to bed. After a space of calm, when we seemed crossing the vortex of a storm, heavy tossing recommenced. I was afraid to allow myself to fall asleep, as my berth was high, and to be pitched out of it might be attended with bruises, if not with fractures. From Friday at noon to Saturday at noon we accomplished sixty-six miles, or an average of less than three miles an hour. I overheard the sailors talking about this storm. The 'Urgent,' according to those that knew her, had never previously experienced anything like it.[1]

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[1] There is, it will be seen, a fair agreement between these impressions and those so vigorously described by a scientific correspondent of the 'Times.'

All through Saturday the wind, though somewhat sobered, blew dead against us. The atmospheric effects were exceedingly fine. The cumuli resembled mountains in shape, and their peaked summits shone as white as Alpine snows. At one place this resemblance was greatly strengthened by a vast area of cloud, uniformly illuminated, and lying like a *névé* below the peaks. From it fell a kind of cloud-river strikingly like a glacier. The horizon at sunset was remarkable—spaces of brilliant green between clouds of fiery red. Rainbows had been frequent throughout the day, and at night a perfectly continuous lunar bow spanned the heavens from side to side. Its colours were feeble; but, contrasted with the black ground against which it rested, its luminousness was extraordinary.

Sunday morning found us opposite to Lisbon, and at midnight we rounded Cape St. Vincent, where the lurching seemed disposed to recommence. Through the kindness of Lieutenant Walton, a cot had been slung for me. It hung between a tiller-wheel and a flue, and at one A.M. I was roused by the banging of the cot against its boundaries. But the wind was now behind us, and we went along at a speed of eleven knots. We felt certain of reaching Cadiz by three. But a new lighthouse came in sight, which some affirmed to be Cadiz Lighthouse, while the surrounding houses were declared to be Cadiz itself. Out of deference to these statements, the navigating lieutenant changed his course, and steered for the place. A pilot came on board, and he informed us that we were before the mouth of the Guadalquivir, and that the lighthouse was that of Cipiòna. Cadiz was still some eighteen miles distant.

We steered towards the city, hoping to get into the harbour before dark. But the pilot was snapped up by another vessel, and we did not get in. We beat about during the night, and in the morning found ourselves about fifteen miles from Cadiz. The sun rose behind the city, and we steered straight into the light. The three-towered cathedral stood in the midst, round which swarmed apparently a multitude of chimney-stacks. A nearer approach showed the chimneys to be small turrets. A pilot was taken on board; for there is a dangerous shoal in the harbour. The appearance of the town as the sun shone upon its white and lofty walls was singularly beautiful. We cast anchor; some officials arrived and demanded a clean bill of health. We had none. They would have nothing to do with us; so the yellow quarantine flag was hoisted, and we waited for permission to land the Cadiz party. After some hours' delay the English consul and vice-consul came on board, and with them a Spanish officer ablaze with gold lace and decorations. Under slight pressure the requisite permission had been granted. We landed our party, and in the afternoon weighed anchor. Thanks to the kindness of our excellent paymaster, I was here transferred to a roomier berth.

Cadiz soon sank beneath the sea, and we sighted in succession Cape Trafalgar, Tarifa, and the revolving light of Ceuta. The water was very calm, and the moon rose in a quiet heaven. She swung with her convex surface downwards, the common boundary between light and shadow being almost horizontal. A pillar of reflected light shimmered up to us from the slightly rippled sea. I had previously noticed the phosphorescence of the water, but to-night it was stronger than usual, especially among the foam at the bows. A bucket let down into the sea brought up a number of the little sparkling organisms which caused the phosphorescence. I caught some of them in my hand. And here an appearance was observed which was new to most of us, and strikingly beautiful to all. Standing at the bow and looking forwards, at a distance of forty or fifty yards from the ship, a number of luminous streamers were seen rushing towards us. On nearing the vessel they rapidly turned, like a comet round its perihelion, placed themselves side by side, and, in parallel trails of light, kept up with the ship. One of them placed itself right in front of the bow as a pioneer. These comets of the sea were joined at intervals by others. Sometimes as many as six at a time would rush at us, bend with extraordinary rapidity round a sharp curve, and afterwards keep us company. I leaned over the bow, and scanned the streamers closely. The frontal portion of each of them revealed the outline of a porpoise. The rush of the creatures through the water had started the phosphorescence, every spark of which was converted by the motion of the retina into a line of light. Each porpoise was thus wrapped in a luminous sheath. The phosphorescence did not cease at the creature's tail, but was carried many porpoise-lengths behind it.

To our right we had the African hills, illuminated by the moon. Gibraltar Rock at length became visible, but the town remained long hidden by a belt of haze. Through this at length the brighter lamps struggled. It was like the gradual resolution of a nebula into stars. As the intervening depth became gradually less, the mist vanished more and more, and finally all the lamps shone through it. They formed a bright foil to the sombre mass of rock above them. The sea was so calm and the scene so lovely that Mr. Huggins and myself stayed on deck till the ship was moored, near midnight. During our walking to and fro a striking enlargement of the disk of Jupiter was observed, whenever the heated air of the funnel came between us and the planet. On passing away from the heated air, the flat dim disk would immediately shrink to a luminous point. The effect was one of visual persistence. The retinal image of the planet was set quivering in all azimuths by the streams of heated air, describing in quick succession minute lines of light, which summed themselves to a disk of sensible area.

At six o'clock next morning, the gun at the Signal Station on the summit of the rock, boomed. At eight the band on board the 'Trafalgar' training-ship, which was in the harbour, struck up the national anthem; and immediately afterwards a crowd of mite like cadets swarmed up the rigging. After the removal of the apparatus belonging to the Gibraltar party we went on shore. Winter was in England when we left, but here we had the warmth of summer. The vegetation was luxuriant—palm-trees, cactuses, and aloes, all ablaze with scarlet flowers. A visit to the Governor was proposed, as an act of necessary courtesy, and I accompanied Admiral Ommaney and Mr. Huggins to 'the Convent,' or Government House. We sent in our cards, waited for a time, and were then conducted by an orderly to his Excellency. He is a fine old man, over six feet high, and of frank military bearing. He received us and conversed with us in a very genial manner. He took us to see his garden, his palms, his shaded promenades, and his orange-trees loaded with fruit, in all of which he took manifest delight. Evidently 'the hero of Kars' had fallen upon quarters after his own heart. He appeared full of good nature, and engaged us on the spot to dine with him that day.

We sought the town-major for a pass to visit the lines. While awaiting his arrival I purchased a stock of white glass bottles, with a view to experiments on the colour of the sea. Mr. Huggins and myself, who wished to see the rock, were taken by Captain Salmond to the library, where a model of Gibraltar is kept, and where we had a capital preliminary lesson. At the library we met Colonel Maberly, a courteous and kindly man, who gave us good advice regarding our excursion. He sent an orderly with us to the entrance of the lines. The orderly handed us over to an ir[illegible]shman, who was directed to show us everything that we desired to see, and to hide nothing from us. We took the 'upper line,' traversed the galleries hewn through the limestone; looked through the embrasures, which opened like doors in the precipice, towards the hills of Spain; reached St. George's Hall, and went still higher, emerging on the summit of one of the noblest cliffs I have ever seen.

Beyond were the Spanish lines, marked by a line of white sentry-boxes; nearer were the English lines, less conspicuously indicated; and between both was neutral ground. Behind the Spanish lines rose the conical hill called the Queen of Spain's Chair. The general aspect of Spain from the rock is bold and rugged. Doubling back from the galleries, we struck upwards towards the crest, reached the Signal Station, where we indulged in 'shandy-gaff' and bread and cheese. Thence to O'Hara's Tower, the highest point of the rock. It was built by a former Governor, who, forgetful of the laws of terrestrial curvature, thought he might look from the tower into the port of Cadiz. The tower is riven, and it may be climbed along the edges of the crack. We got to the top of it; thence descended the curious Mediterranean Stair—a zigzag, mostly of steps down a steeply falling slope, amid palmetto brush, aloes, and prickly pear.

Passing over the Windmill Hill, we were joined at the 'Governor's Cottage' by a car, and drove afterwards to the lighthouse at Europa Point. The tower was built, I believe, by Queen Adelaide, and it contains a fine dioptric apparatus of the first order, constructed by Messrs. Chance, of Birmingham. At the appointed hour we were at the Convent. During dinner the same genial traits which appeared in the morning were still more conspicuous. The freshness of the Governor's nature showed itself best when he spoke of his old antagonist in arms, Mouravieff. Chivalry in war is consistent with its stern prosecution.

These two men were chivalrous, and after striking the last blow became friends for ever. Our kind and courteous reception at Gibraltar is a thing to be remembered with pleasure.

On December 15 we committed ourselves to the Mediterranean. The views of Gibraltar with which we are most acquainted represent it as a huge ridge; but its aspect, end on, both from the Spanish lines and from the other side, is truly noble. There is a sloping bank of sand at the back of the rock, which I was disposed to regard simply as the *débris* of the limestone. I wished to let myself down upon it, but had not the time. My friend Mr. Busk, however, assures me that it is silica, and that the same sand constitutes the adjacent neutral ground. There are theories afloat as to its having been blown from Sahara. The Mediterranean throughout this first day, and indeed throughout the entire voyage to Oran, was of a less deep blue than the Atlantic. Possibly the quantity of organisms may have modified the colour. At night the phosphorescence was startling, breaking with the suddenness of a snapped spring along the crests of the waves formed by the port and starboard bows. Its strength was not uniform. Having flashed brilliantly for a time, it would in part subside, and afterwards regain its vigour. Several large phosphorescent masses of weird appearance also floated past.

On the morning of the 16th we sighted the fort and lighthouse of Marsa el Kibir, and beyond them the white walls of Oran lying in the bight of a bay, sheltered by dominant hills. The sun was shining brightly; during our whole voyage we had not had so fine a day. The wisdom which had led us to choose Oran as our place of observation seemed demonstrated. A rather excitable pilot came on board, and he guided us in behind the Mole, which had suffered much damage last year from an unexplained outburst of waves from the Mediterranean. Both port and bow anchors were cast in deep water. With three huge hawsers the ship's stern was made fast to three gun-pillars fixed in the Mole; and here for a time the 'Urgent' rested from her labours.

M. Janssen, who had rendered his name celebrated by his observations of the eclipse in India in 1868, when he showed the solar flames to be eruptions of incandescent hydrogen, was already encamped in the open country about eight miles from Oran. On December 2 he had quitted Paris in a balloon, with a strong young sailor as his assistant, had descended near the mouth of the Loire, seen M. Gambetta, and received from him encouragement and aid. On the day of our arrival his encampment was visited by Mr. Huggins, and the kind and courteous Engineer of the Port drove me subsequently, in his own phaeton, to the place. It bore the best repute as regards freedom from haze and fog, and commanded an open outlook; but it was inconvenient for us on account of its distance from the ship. The place next in repute was the railway station, between two and three miles distant from the Mole. It was inspected, but, being enclosed, was abandoned for an eminence in an adjacent garden, the property of Mr. Hinshelwood, a Scotchman who had settled some years previously as an Esparto merchant in Oran.[1] He, in the most liberal manner, placed his ground at the disposition of the party. Here the tents were pitched, on the Saturday, by Captain Salmond and his intelligent corps of sappers, the instruments being erected on the Monday under cover of the tents.

Close to the railway station runs a new loopholed wall of defence, through which the highway passes into the open country. Standing on the highway, and looking southwards, about twenty yards to the right is a small bastionet, intended to carry a gun or two. Its roof I thought would form an admirable basis for my telescope, while the view of the surrounding country was unimpeded in all directions. The authorities kindly allowed me the use of this bastionet. Two men, one a blue-jacket named Elliot, and the other a marine named Hill, were placed at my disposal by Lieutenant Walton; and, thus aided, on Monday morning I mounted my telescope. The instrument was new to me, and some hours of discipline were spent in mastering all the details of its manipulation.

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[1] Esparto is a kind of grass now much used in the manufacture of paper.

Mr. Huggins joined me, and we visited together the Arab quarter of Oran. The flat-roofed houses appeared very clean and white. The street was filled with loiterers, and the thresholds were occupied by picturesque groups. Some of the men were very fine. We saw many straight, manly fellows who must have been six feet four in height. They passed us with perfect indifference, evincing no anger, suspicion, or curiosity, hardly caring in fact to glance at us as we passed. In one instance only during my stay at Oran was I spoken to by an Arab. He was a tall, good-humoured fellow, who came smiling up to me, and muttered something about 'les Anglais.' The mixed population of Oran is picturesque in the highest degree: the Jews, rich and poor, varying in their costumes as their wealth varies; the Arabs more picturesque still, and of all shades of complexion—the negroes, the Spaniards, the French, all grouped together, and each preserving their own individuality, formed a picture intensely interesting to me.

On Tuesday, the 20th, I was early at the bastionet. The night had been very squally. The sergeant of the sappers took charge of our key, and on Tuesday morning Elliot went for it. He brought back the intelligence that the tents had been blown down, and the instruments overturned. Among these was a large and valuable equatorial from the Royal Observatory, Greenwich. It seemed hardly possible that this instrument, with its wheels and verniers and delicate adjustments, could have escaped uninjured from such a fall. This, however, was the case; and during the day all the overturned instruments were restored to their places, and found to be in practical working order. This and the following day were devoted to incessant schooling. I had come out as a general star-gazer, and not with the intention of devoting myself to the observation of any particular phenomenon. I wished to see the whole—the first contact, the advance of the moon, and the successive swallowing up of the solar spots, the breaking of the last line of crescent by the lunar mountains into Bailey's beads, the advance of the shadow through the air, the appearance of the corona and prominences at the moment of totality, the radiant streamers of the corona, the internal structure of the flames, a glance through a polariscope, a sweep round the landscape with the naked eye, the reappearance of the solar limb through Bailey's beads, and, finally, the retreat of the lunar shadow through the air.

I was provided with a telescope of admirable definition, mounted, adjusted, packed, and most liberally placed at my disposal by Mr. Warren De La Rue. The telescope grasped the whole of the sun, and a considerable portion of the space surrounding it. But it would not take in the extreme limits of the corona. For this I had lashed on to the large telescope a light but powerful instrument, constructed by Ross, and lent to me by Mr. Huggins. I was also furnished with an excellent binocular by Mr. Dallmeyer. In fact, no man could have been more efficiently supported. It required a strict parcelling out of the interval of totality to embrace in it the entire series of observations. These, while the sun remained visible, were to be made with an unsilvered diagonal eyepiece, which reflected but a small fraction of the sun's light, this fraction being still further toned down by a dark glass. At the moment of totality the dark glass was to be removed, and a silver reflector pushed in, so as to get the maximum of light from the corona and prominences. The time of totality was distributed as follows:

1. Observe approach of shadow through the air: totality.	
2. Telescope	30 seconds.
3. Finder	30 seconds.
4. Double image prism	15 seconds.
5. Naked eye	10 seconds.
6. Finder or binocular	20 seconds.
7. Telescope	20 seconds.
8. Observe retreat of shadow.	

In our rehearsals Elliot stood beside me, watch in hand, and furnished with a lantern. He called out at the end of each interval, while I moved from telescope to finder, from finder to polariscope, from polariscope to naked eye, from naked eye back to finder, from finder to telescope, abandoning the instrument finally to observe the retreating shadow. All this we went over twenty times, while looking at the actual sun, and keeping him in the middle of the field. It was my object to render the repetition of the lesson so mechanical as to leave no room for flurry, forgetfulness, or excitement. Volition was not to be called upon, nor judgment exercised, but a well-beaten path of routine was to be followed. Had the opportunity occurred, I think the programme would have been strictly carried out.

But the opportunity did not occur. For several days the weather had been ill-natured. We had wind so strong as to render the hawsers at the stern of the 'Urgent' as rigid as iron, and to destroy the navigating lieutenant's sleep. We had clouds, a thunder-storm, and some rain.

Still the hope was held out that the atmosphere would cleanse itself, and if it did we were promised air of extraordinary limpidity. Early on the 22nd we were all at our posts. Spaces of blue in the early morning gave us some encouragement, but all depended on the relation of these spaces to the surrounding clouds. Which of them were to grow as the day advanced? The wind was high, and to secure the steadiness of my instrument I was forced to retreat behind a projection of the bastionet, place stones upon its stand, and, further, to avail myself of the shelter of a sail. My practised men fastened the sail at the top, and loaded it with boulders at the bottom. It was tried severely, but it stood firm.

The clouds and blue spaces fought for a time with varying success. The sun was hidden and revealed at intervals, hope oscillating in synchronism with the changes of the sky. At the moment of first contact a dense cloud intervened; but a minute or two afterwards the cloud had passed, and the encroachment of the black body of the moon was evident upon the solar disk. The moon marched onward, and I saw it at frequent intervals; a large group of spots were approached and swallowed up. Subsequently I caught sight of the lunar limb as it cut through the middle of a large spot. The spot was not to be distinguished from the moon, but rose like a mountain above it. The clouds, when thin, could be seen as grey scud drifting across the black surface of the moon; but they thickened more and more, and made the intervals of clearness scantier. During these moments I watched with an interest bordering upon fascination the march of the silver sickle of the sun across the field of the telescope. It was so sharp and so beautiful. No trace of the lunar limb could be observed beyond the sun's boundary. Here, indeed, it could only be relieved by the corona, which was utterly cut off by the dark glass. The blackness of the moon beyond the sun was, in fact, confounded with the blackness of space.

Beside me was Elliot with the watch and lantern, while Lieutenant Archer, of the Royal Engineers, had the kindness to take charge of my note-book. I mentioned, and he wrote rapidly down, such things as seemed worthy of remembrance. Thus my hands and mind were entirely free; but it was all to no purpose. A patch of sunlight fell and rested upon the landscape some miles away. It was the only illuminated spot within view. But to the north-west there was still a space of blue which might reach us in time. Within seven minutes of totality another space towards the zenith became very dark. The atmosphere was, as it were, on the brink of a precipice; it was charged with humidity, which required but a slight chill to bring it down in clouds. This was furnished by the withdrawal of the solar beams; the clouds did come down, covering up the space of blue on which our hopes had so long rested. I abandoned the telescope and walked to and fro, like a caged leopard. As the moment of totality approached, the descent towards darkness was as obvious as a falling stone. I looked towards a distant ridge, where the darkness would first appear. At the moment a fan of beams, issuing from the hidden sun, was spread out over the southern heavens. These beams are bars of alternate light and shade, produced in illuminated haze by the shadows of floating cloudlets of varying density. The beams are practically parallel, but by an effect of perspective they appear divergent, having the sun, in fact, for their point of convergence. The darkness took possession of the ridge referred to, lowered upon M. Janssen's observatory, passed over the southern heavens, blotting out the beams as if a sponge had been drawn across them. It then took possession of three spaces of blue sky in the south-eastern atmosphere.

I again looked towards the ridge. A glimmer as of day-dawn was behind it, and immediately afterwards the fan of beams, which had been for more than two minutes absent, revived. The eclipse of 1870 had ended, and, as far as the corona was concerned, we had been defeated.

Even in the heart of the eclipse the darkness was by no means perfect. Small print could be read. In fact, the clouds which rendered the day a dark one, by scattering light into the shadow, rendered the darkness less intense than it would have been had the atmosphere been without cloud. In the more open spaces I sought for stars, but could find none. There was a lull in the wind before and after totality, but during the totality the wind was strong. I waited for some time on the bastionet, hoping to get a glimpse of the moon on the opposite border of the sun, but in vain. The clouds continued, and some rain fell. The day brightened somewhat afterwards, and, having packed all up, in the sober twilight Mr. Crookes and myself climbed the heights above the fort of Vera Cruz. From this eminence we had a very noble view over the Mediterranean and the flanking African hills. The sunset was remarkable, and the whole outlook exceedingly fine.

The able and well-instructed medical officer of the 'Urgent,' Mr. Goodman, observed the following temperatures during the progress of the eclipse:

Hour	Deg.	Hour	Deg.
11.45	56	12.43	51
11.55	55	1.5	52
12.10	54	1.27	53
12.37	53	1.44	56
12.39	52	2.10	57

The minimum temperature occurred some minutes after totality, when a slight rain fell.

The wind was so strong on the 23rd that Captain Henderson would not venture out. Guided by Mr.

Goodman, I visited a cave scooped into a remarkable stratum of shell-breccia, and, thanks to my guide, secured specimens. Mr. Busk informs me that a precisely similar breccia is found at Gibraltar, at approximately the same level. During the afternoon, Admiral Ommaney and myself drove to the fort of Marsa el Kibir. The fortification is of ancient origin, the Moorish arches being still there in decay, but the fort is now very strong. About four or five hundred fine-looking dragoons were looking after their horses, waiting for a lull to enable them to embark for France. One of their officers was wandering in a very solitary fashion over the fort. We had some conversation with him. He had been at Sedan, had been taken prisoner, but had effected his escape. He shook his head when we spoke of the termination of the war, and predicted its long continuance. There was bitterness in his tone as he spoke of the charges of treason so lightly levelled against French commanders. The green waves raved round the promontory on which the fort stands, smiting the rocks, breaking into foam, and jumping, after impact, to a height of a hundred feet and more into the air. On our return our vehicle broke down through the loss of a wheel. The Admiral went on board, while I hung long over the agitated sea. The little horses of Oran well merit a passing word. Their speed and endurance, which are both heavily drawn upon by their drivers, are extraordinary.

The wind sinking, we lifted anchor on the 24th. For some hours we went pleasantly along; but during the afternoon the storm revived, and it blew heavily against us all the night. When we came opposite the Bay of Almeria, on the 25th, the captain turned the ship, and steered into the bay, where, under the shadow of the Sierra Nevada, we passed Christmas night in peace. Next morning 'a rose of dawn' rested on the snows of the adjacent mountains, while a purple haze was spread over the lower hills. I had no notion that Spain possessed so fine a range of mountains as the Sierra Nevada. The height is considerable, but the form also is such as to get the maximum of grandeur out of the height. We weighed anchor at eight A.M., passing for a time through shoal water, the bottom having been evidently stirred up. The adjacent land seemed eroded in a remarkable manner. It has its floods, which excavate these valleys and ravines, and leave those singular ridges behind. Towards evening I climbed the mainmast, and, standing on the cross-trees, saw the sun set amid a blaze of fiery clouds. The wind was strong and bitterly cold, and I was glad to slide to the deck along a rope, which stretched from the mast-head to the ship's side. That night we cast anchor beside the Mole of Gibraltar.

On the morning of the 27th, in company with two friends, I drove to the Spanish lines, with the view of seeing the rock from that side. It is an exceedingly noble mass. The Peninsular and Oriental mail-boat had been signalled and had come. Heavy duties called me homeward, and by transferring myself from the 'Urgent' to the mail-steamer I should gain three days. I hired a boat, rowed to the steamer, learned that she was to start at one, and returned with all speed to the 'Urgent.' Making known to Captain Henderson my wish to get away, he expressed doubts as to the possibility of reaching the mail-steamer in time. With his accustomed kindness, he, however, placed a boat at my disposal. Four hardy fellows and one of the ship's officers jumped into it; my luggage, hastily thrown together, was tumbled in afterwards, and we were immediately on our way. We had nearly four miles to row in about twenty minutes; but we hoped the mail-boat might not be punctual. For a time we watched her anxiously; there was no motion; we came nearer, but the flags were not yet hauled in. The men put forth all their strength, animated by the exhortations of the officer at the helm. The roughness of the sea rendered their efforts to some extent nugatory: still we were rapidly approaching the steamer. At length she moved, punctual almost to the minute, at first slowly, but soon with quickened pace. We turned to the left, so as to cut across her bows. Five minutes' pull would have brought us up to her. The officer waved his cap and I my hat. 'If they could only see us, they might back to us in a moment.' But they did not see us, or if they did, they paid no attention to us. I returned to the 'Urgent,' discomfited, but grateful to the fine fellows who had wrought so hard to carry out my wishes.

Glad of the quiet, in the sober afternoon I took a walk towards Europa Point. The sky darkened and heavy squalls passed at intervals. Private theatricals were at the Convent, and the kind and courteous Governor had sent cards to the eclipse party. I failed in my duty in not going. St. Michael's Cave is said to rival, if it does not outrival, the Mammoth Cave of Kentucky. On the 28th Messrs. Crookes, Carpenter, and myself, guided by a military policeman who understood his work, explored the cavern. The mouth is about 1,100 feet above the sea. We zigzagged up to it, and first were led into an aperture in the rock, at some height above the true entrance of the cave. In this upper cavern we saw some tall and beautiful stalactite pillars.

The water drips from the roof charged with bicarbonate of lime. Exposed to the air, the carbonic acid partially escapes, and the simple carbonate of lime, which is hardly at all soluble in water, deposits itself as a solid, forming stalactites and stalagmites. Even the exposure of chalk or limestone water to the open air partially softens it. A specimen of the Redbourne water exposed by Messrs. Graham, Miller, and Hofmann, in a shallow basin, fell from eighteen degrees to nine degrees of hardness. The softening process of Clark is virtually a hastening of the natural process. Here, however, instead of being permitted to evaporate, half the carbonic acid is appropriated by lime, the half thus taken up, as well as the remaining half, being precipitated. The solid precipitate is permitted to sink, and the clear supernatant liquid is limpid soft water.

We returned to the real mouth of St. Michael's Cave, which is entered by a wicket. The floor was somewhat muddy, and the roof and walls were wet. We were soon in the midst of a natural temple, where tall columns sprang complete from floor to roof, while incipient columns were growing to meet each other, upwards and downwards. The water which trickles from the stalactite, after having in part yielded up its carbonate of lime, falls upon the floor vertically underneath, and there builds the stalagmite. Consequently, the pillars grow from above and below simultaneously, along the same vertical. It is easy to distinguish the stalagmitic from the stalactitic portion of the pillars. The former is always divided into short segments by protuberant rings, as if deposited periodically, while the latter presents a uniform surface. In some cases the points of inverted cones of stalactite rested on the centres of pillars of stalagmite. The process of solidification and the architecture were alike beautiful.

We followed our guide through various branches and arms of the cave, climbed and descended steps, halted at the edges of dark shafts and apertures, and squeezed ourselves through narrow passages. From time to time we halted, while Mr. Crookes illuminated with ignited magnesium wire, the roof, columns, dependent spears, and graceful drapery of the stalactites. Once, coming to a magnificent cluster of icicle-like spears, we helped ourselves to specimens. There was some difficulty in detaching the more delicate ones, their fragility was so great. A consciousness of vandalism, which smote me at the time, haunts me still; for, though our requisitions were moderate, this beauty ought not to be at all invaded. Pendent from the roof, in their natural habitat, nothing can exceed their delicate beauty; they *live*, as it were, surrounded by organic connections. In London they are curious, but not beautiful. Of gathered shells Emerson writes:

> I wiped away the weeds and foam,
> And brought my sea-born treasures home:
> But the poor, unsightly, noisome things
> Had left their beauty on the shore,
> With the sun, and the sand, and the wild uproa

The promontory of Gibraltar is so burrowed with caverns that it has been called the Hill of Caves. They are apparently related to the geologic disturbances which the rock has undergone. The earliest of these is the tilting of the once horizontal strata. Suppose a force of torsion to act upon the promontory at its southern extremity near Europa Point, and suppose the rock to be of a partially yielding character; such a force would twist the strata into screw-surfaces, the greatest amount of twisting being endured near the point of application of the force. Such a twisting the rock appears to have suffered; but instead of the twist fading gradually and uniformly off, in passing from south to north, the want of uniformity in the material has produced lines of dislocation where there are abrupt changes in the amount of twist. Thus, at the northern end of the rock the dip to the west is nineteen degrees; in the Middle Hill it is thirty-eight degrees; in the centre of the South Hill, or Sugar Loaf, it is fifty-seven degrees. At the southern extremity of the Sugar Loaf the strata are vertical, while farther to the south they actually turn over and dip to the east.

The rock is thus divided into three sections, separated from each other by places of dislocation, where the strata are much wrenched and broken. These are called the Northern and Southern Quebrada, from the Spanish 'Tierra Quebrada,' or broken ground. It is at these places that the inland caves of Gibraltar are almost exclusively found. Based on the observations of Dr. Falconer and himself, an excellent and most interesting account of these caves, and of the human remains and works of art which they contain, was communicated by Mr. Busk to the meeting of the Congress of Prehistoric Archæology at Norwich, and afterwards printed in the 'Transactions' of the Congress.[1] Long subsequently to the operation of the twisting force just referred to, the promontory underwent various changes of level. There are sea-terraces and layers of shell-breccia along its flanks, and numerous caves which, unlike the inland ones, are the product of marine erosion. The Ape's Hill, on the African side of the strait, Mr. Busk informs me has undergone similar disturbances.[2]

In the harbour of Gibraltar, on the morning of our departure, I resumed a series of observations on the colour of the sea. On the way out a number of specimens had been collected, with a view to subsequent examination. But the bottles were claret bottles, of doubtful purity. At Gibraltar, therefore, I purchased fifteen white glass bottles, with ground glass stoppers, and at Cadiz, thanks to the friendly guidance of Mr. Cameron, I secured a dozen more. These seven-and-twenty bottles were filled with water, taken at different places between Oran and Spithead.

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[1] In this essay Mr. Busk refers to the previous labours of Mr. Smith, of Jordan Hill, to whom we owe most of our knowledge of the geology of the rock.

[2] No one can rise from the perusal of Mr. Busk's paper without a feeling of admiration for the principal discoverer and indefatigable explorer of the Gibraltar caves, the late Captain Frederick Brome.

And here let me express my warmest acknowledgments to Captain Henderson, the commander of H.M.S. 'Urgent,' who aided me in my observations in every possible way. Indeed, my thanks are due to all the officers for their unfailing courtesy and help. The captain placed at my disposal his own coxswain, an intelligent fellow named Thorogood, who skilfully attached a cord to each bottle, weighted it with lead, cast it into the sea, and, after three successive rinsings, filled it under my own eyes. The contact of jugs, buckets, or other vessels was thus avoided; and even the necessity of pouring out the water, afterwards, through the dirty London air.

The mode of examination applied to these bottles has been already described.[1] The liquid is illuminated by a powerfully condensed beam, its condition being revealed through the light scattered by its suspended particles. 'Care is taken to defend the eye from the access of all other light, and, thus defended, it becomes an organ of inconceivable delicacy.' Were water of uniform density perfectly free from suspended matter, it would, in my opinion, scatter no light at all. The track of a luminous beam could not be seen in such water. But 'an amount of impurity so infinitesimal as to be scarcely expressible in numbers, and the individual particles of which are so small as wholly to elude the microscope, may, when examined by the method alluded to, produce not only sensible, but striking, effects upon the eye.'

The results of the examination of nineteen bottles filled at various places between Gibraltar and Spithead, are here tabulated:

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[1] On Dust and Disease, pp. 156, 157.

No.	Locality	Colour of Sea	Appearance in Luminous Beam
1	Gibraltar Harbour	Green	Thick with fine particles
2	Two miles from Gibraltar	Clearer green	Thick with very fine particles
3	Off Cabreta Point	Bright green	Still thick, but less so
4	Off Cabreta Point	Black-indigo	Much less thick, very pure
5	Off Tarifa	Undecided	Thicker than No. 4
6	Beyond Tarifa	Cobalt-blue	Much purer than No. 5
7	Twelve miles from Cadiz	Yellow-green	Very thick
8	Cadiz Harbour	Yellow-green	Exceedingly thick
9	Fourteen miles from Cadiz	Yellow-green	Thick, but less so
10	Fourteen miles from Cadiz	Bright green	Much less thick
11	Between Capes St. Mary and Vincent	Deep indigo	Very little matter, very pure
12	Off the Burlings	Strong green	Thick, with fine matter
13	Beyond the Burlings	Indigo	Very little matter, pure
14	Off Cape Finisterre	Undecided	Less pure
15	Bay of Biscay	Black-indigo	Very little matter, very pure
16	Bay of Biscay	Indigo	Very fine matter. Iridescent
17	Off Ushant	Dark green	A good deal of matter
18	Off St. Catherine's	Yellow-green	Exceedingly thick
19	Spithead	Green	Exceedingly thick

Here we have three specimens of water, described as green, a clearer green, and bright green, taken in Gibraltar Harbour, at a point two miles from the harbour, and off Cabreta Point. The home examination showed the first to be thick with suspended matter, the second less thick, and the third still less thick. Thus the green brightened as the suspended matter diminished in amount.

Previous to the fourth observation our excellent navigating lieutenant, Mr. Brown, steered along the coast, thus avoiding the adverse current which sets in, through the Strait, from the Atlantic to the Mediterranean. He was at length forced to cross the boundary of the Atlantic current, which was defined with extraordinary sharpness. On the one side of it the water was a vivid green, on the other a deep blue. Standing at the bow of the ship, a bottle could be filled with blue water, while at the same moment a bottle cast from the stern could be filled with green water. Two bottles were secured, one on each side of this remarkable boundary. In the distance the Atlantic had the hue called ultramarine; but looked fairly down upon, it was of almost inky blackness—black qualified by a trace of indigo.

What change does the home examination here reveal? In passing to indigo, the water becomes suddenly augmented in purity, the suspended matter becoming suddenly less. Off Tarifa, the deep indigo disappears, and the sea is undecided in colour. Accompanying this change, we have a rise in the quantity of suspended matter. Beyond Tarifa, we change to cobalt-blue, the suspended matter falling at the same time in quantity. This water is distinctly purer than the green. We approach Cadiz, and at twelve miles from the city get into yellow-green water; this the London examination shows to be thick with suspended matter. The same is true of Cadiz harbour, and also of a point fourteen miles from Cadiz in the homeward direction. Here there is a sudden change from yellow-green to a bright emerald-green, and accompanying the change a sudden fall in the quantity of suspended matter. Between Cape St. Mary and Cape St. Vincent the water changes to the deepest indigo, a further diminution of the suspended matter being the concomitant phenomenon.

We now reach the remarkable group of rocks called the Burlings, and find the water between the shore and the rocks a strong green; the home examination shows it to be thick with fine matter. Fifteen or twenty miles beyond the Burlings we come again into indigo water, from which the suspended matter has in great part disappeared. Off Cape Finisterre, about the place where the 'Captain' went down, the water becomes green, and the home examination pronounces it to be thicker. Then we enter the Bay of Biscay, where the indigo resumes its power, and where the home examination shows the greatly augmented purity of the water. A second specimen of water, taken from the Bay of Biscay, held in suspension fine particles of a peculiar kind; the size of them was such as to render the water richly iridescent. It showed itself green, blue, or salmon-coloured, according to the direction of the line of vision. Finally, we come to our last two bottles, the one taken opposite St. Catherine's lighthouse, in the Isle of Wight, the other at Spithead. The sea at both these places was green, and both specimens, as might be expected, were pronounced by the home examination to be thick with suspended matter.

Two distinct series of observations are here referred to —the one consisting of direct observations of the colour of the sea, conducted during the voyage from Gibraltar to Portsmouth; the other carried out in the laboratory of the Royal Institution. And here it is to be noted that in the home examination I never knew what water was placed in my hands. The labels, with the names of the localities written upon them, had been tied up, all information regarding the source of the water being thus held back. The bottles were simply numbered, and not till all of them had been examined, and described, were the labels opened, and the locality and sea-colour corresponding to the various specimens ascertained. The home observations, therefore, must have been perfectly unbiassed, and they clearly establish the association of the green colour with fine suspended matter, and of the ultramarine colour, and more especially of the black-indigo hue of the Atlantic, with the comparative absence of such matter.

So much for mere observation; but what is the cause of the dark hue of the deep ocean?[1] A preliminary remark or two will clear our way towards an explanation. Colour resides in white light, appearing generally when any constituent of the white light is withdrawn. The hue of a purple liquid, for example, is immediately accounted for by its action on a spectrum. It cuts out the yellow and green, and allows the red and blue to pass through. The blending of these two colours produces the purple. But while such a liquid attacks with special energy the yellow and green, it enfeebles the whole spectrum. By increasing the thickness of the stratum we may absorb the whole of the light. The colour of a blue liquid is similarly accounted for. It first extinguishes the red; then, as the thickness augments, it attacks the orange, yellow, and green in succession; the blue alone finally remaining. But even it might be extinguished by a sufficient depth of liquid.

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[1] A note, written to me on October 22, by my friend Canon Kingsley, contains the following reference to this point: 'I have never seen the Lake of Geneva, but I thought of the brilliant dazzling dark blue of the mid-Atlantic under the sunlight, and its black-blue under cloud, both so solid that one might leap off the sponson on to it without fear; this was to me the most wonderful thing which I saw on my voyages to and from the West Indies.'

And now we are prepared for a brief, but tolerably complete, statement of that action of sea-water upon light, to which it owes its darkness. The spectrum embraces three classes of rays—the thermal, the visual, and the chemical. These divisions overlap each other; the thermal rays are in part visual, the visual rays in part chemical, and *vice versâ*. The vast body of thermal rays lie beyond the red, being invisible. These rays are attacked with exceeding energy by water. They are absorbed close to the surface of the sea, and are the great agents in evaporation. At the same time the whole spectrum suffers enfeeblement; water attacks all its rays, but with different degrees of energy. Of the visual rays, the red are first extinguished. As the solar beam plunges deeper into the sea, orange follows red, yellow follows orange, green follows yellow, and the various shades of blue, where the water is deep enough, follow green. Absolute extinction of the solar beam would be the consequence if the water were deep and uniform. If it contained no suspended matter, such water would be as black as ink. A reflected glimmer of ordinary light would reach us from its surface, as it would from the surface of actual ink; but no light, hence no colour, would reach us from the body of the water.

In very clear and deep sea-water this condition is approximately fulfilled, and hence the extraordinary darkness of such water. The indigo, already referred to, is, I believe, to be ascribed in part to the suspended matter, which is never absent, even in the purest natural water; and in part to the slight reflection of the light from the limiting surfaces of strata of different densities. A modicum of light is thus thrown back to the eye, before the depth necessary to absolute extinction has been attained. An effect precisely similar occurs under the moraines of glaciers. The ice here is exceptionally compact, and, owing to the absence of the internal scattering common in bubbled ice, the light plunges into the mass, where it is extinguished, the perfectly clear ice presenting an appearance of pitchy blackness.[1]

The green colour of the sea has now to be accounted for; and here, again, let us fall back upon the sure basis of experiment. A strong white dinner-plate had a lead weight securely fastened to it. Fifty or sixty yards of strong hempen line were attached to the plate. My assistant, Thorogood, occupied a boat, fastened as usual to the davits of the 'Urgent,' while I occupied a second boat nearer the stern of the ship. He cast the plate as a mariner heaves the lead, and by the time it had reached me it had sunk a considerable depth in the water. In all cases the hue of this plate was green; even when the sea was of the darkest indigo, the green was vivid and pronounced. I could notice the gradual deepening of the colour as the plate sank, but at its greatest depth, even in indigo water, the colour was still a blue-green.[1]

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[1] I learn from a correspondent that certain Welsh tarns, which are reputed bottomless, have this inky hue.

Other observations confirmed this one. The 'Urgent' is a screw steamer, and right over the blades of the screw was an orifice called the screw-well, through which one could look from the poop down upon the screw. The surface-glimmer, which so pesters the eye, was here in a great measure removed. Midway down, a plank crossed the screw-well from side to side; on this I placed myself and observed the action of the screw underneath. The eye was rendered sensitive by the moderation of the light; and, to remove still further all disturbing causes, Lieutenant Walton had a sail and tarpaulin thrown over the mouth of the well. Underneath this I perched myself and watched the screw. In an indigo sea the play of colour was indescribably beautiful, and the contrast between the water, which had the screw-blades, and that which had the bottom of the ocean, as a background, was extraordinary. The one was of the most brilliant green, the other of the deepest ultramarine. The surface of the water above the screw-blade was always ruffled. Liquid lenses were thus formed, by which the coloured light was withdrawn from some places and concentrated upon others, the water flashing with metallic lustre. The screw-blades in this case played the part of the dinner-plate in the former case, and there were other instances of a similar kind. The white bellies of porpoises showed the green hue, varying in intensity as the creatures swung to and fro between the surface and the deeper water. Foam, at a certain depth below the surface, is also green. In a rough sea the light which has penetrated the summit of a wave sometimes reaches the eye, a beautiful green cap being thus placed upon the wave, even in indigo water.

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[1] In no case, of course, is the green pure, but a mixture of green and blue.

But how is this colour to be connected with the suspended particles? Take the dinner-plate which showed so brilliant a green when thrown into indigo water. Suppose it to diminish in size, until it reaches an almost microscopic magnitude. It would still behave substantially as the larger plate, sending to the eye its modicum of green light. If the plate, instead of being a large coherent mass, were ground to a powder sufficiently fine, and in this condition diffused through the clear sea-water, it would send green light to the eye. In fact, the suspended particles which the home examination reveals, act in all essential particulars like the plate, or like the screw-blades, or like the foam, or like the bellies of the porpoises. Thus I think the greenness of the sea is physically connected with the matter which it holds in suspension.

We reached Portsmouth on January 5, 1871. Then ended a voyage which, though its main object was not realised, has left behind it pleasant memories, both of the aspects of nature and the kindliness of men.

VII.

NIAGARA.

1872.

IT is one of the disadvantages of reading books about natural scenery that they fill the mind with pictures, often exaggerated, often distorted, often blurred, and, even when well drawn, injurious to the freshness of first impressions. Such has been the fate of most of us with regard to the Falls of Niagara. There was little accuracy in the estimates of the first observers of the cataract. Startled by an exhibition of power so novel and so grand, emotion leaped beyond the control of the judgment, and gave currency to notions which have often led to disappointment.

A record of a voyage in 1535 by a French mariner named Jacques Cartier, contains, it is said, the first printed allusion to Niagara. In 1603 the first map of the district was constructed by a Frenchman named Champlain. In 1648 the Jesuit Rageneau, in a letter to his superior at Paris, mentions Niagara as 'a cataract of frightful height.'[1] In the winter of 1678 and 1679 the cataract was visited by Father Hennepin, and described in a book dedicated 'to the King of Great Britain.' He gives a drawing of the waterfall, which shows that serious changes have taken place since his time. He describes it as 'a great and prodigious cadence of water, to which the universe does not offer a parallel.' The height of the fall, according to Hennepin, was more than 600 feet. 'The waters,' he says, 'which fall from this great precipice do foam and boil in the most astonishing manner, making a noise more terrible than that of thunder. When the wind blows to the south its frightful roaring may be heard for more than fifteen leagues.' The Baron la Hontan, who visited Niagara in 1687, makes the height 800 feet. In 1721 Charlevois, in a letter to Madame de Maintenon, after referring to the exaggerations of his predecessors, thus states the result of his own observations: 'For my part, after examining it on all sides, I am inclined to think that we cannot allow it less than 140 or 150 feet,'—a remarkably close estimate. At that time, viz. a hundred and fifty years ago, it had the shape of a horseshoe, and reasons will subsequently be given for holding that this has been always the form of the cataract, from its origin to its present site.

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[1] From an interesting little book presented to me at Brooklyn by its author, Mr. Holly, some of these data are derived: Hennepin, Kalm, Bakewell, Lyell, Hall, and others I have myself consulted.

As regards the noise of the fall, Charlevois declares the accounts of his predecessors, which, I may say, are repeated to the present hour, to be altogether extravagant. He is perfectly right. The thunders of Niagara are formidable enough to those who really seek them at the base of the Horseshoe Fall; but on the banks of the river, and particularly above the fall, its silence, rather than its noise, is surprising. This arises, in part, from the lack of resonance; the surrounding country being flat, and therefore furnishing no echoing surfaces to reinforce the shock of the water. The resonance from the surrounding rocks causes the Swiss Reuss at the Devil's Bridge, when full, to thunder more loudly than the Niagara.

On Friday, November 1, 1872, just before reaching the village of Niagara Falls, I caught, from the railway train, my first glimpse of the smoke of the cataract. Immediately after my arrival I went with a friend to the northern end of the American Fall. It may be that my mood at the time toned down the impression produced by the first aspect of this grand cascade; but I felt nothing like disappointment, knowing, from old experience, that time and close acquaintanceship, the gradual interweaving of mind and nature, must powerfully influence my final estimate of the scene. After dinner we crossed to Goat Island, and, turning to the right, reached the southern end of the American Fall. The river is here studded with small islands. Crossing a wooden bridge to Luna Island, and clasping a tree which grows near its edge, I looked long at the cataract, which here shoots down the precipice like an avalanche of foam. It grew in power and beauty. The channel spanned by the wooden bridge was deep, and the river there doubled over the edge of the precipice, like the swell of a muscle, unbroken. The ledge here overhangs, the water being poured out far beyond the base of the precipice. A space, called the Cave of the Winds, is thus enclosed between the wall of rock and the falling water.

Goat Island ends in a sheer dry precipice, which connects the American and Horseshoe Falls. Midway between both is a wooden hut, the residence of the guide to the Cave of the Winds, and from the hut a winding staircase, called Biddle's Stair, descends to the base of the precipice. On the evening of my arrival I went down this stair, and wandered along the bottom of the cliff. One well-known factor in the formation and retreat of the cataract was immediately observed. A thick layer of limestone formed the upper portion of the cliff. This rested upon a bed of soft shale, which extended round the base of the cataract. The violent recoil of the water against this yielding substance crumbles it away, undermining the ledge above, which, unsupported, eventually breaks off, and produces the observed recession.

At the southern extremity of the Horseshoe is a promontory, formed by the doubling back of the gorge, excavated by the cataract, and into which it plunges. On the promontory stands a stone building, called the Terrapin Tower, the door of which had been nailed up because of the decay of the staircase within it. Through the kindness of Mr. Townsend, the superintendent of Goat Island, the door was opened for me. From this tower, at all hours of the day, and at some hours of the night, I watched and listened to the Horseshoe Fall. The river here is evidently much deeper than the American branch; and instead of bursting into foam where it quits the ledge, it bends solidly over, and falls in a continuous layer of the most vivid green. The tint is not uniform; long stripes of deeper hue alternating with bands of brighter colour. . Close to the ledge over which the water rolls, foam is generated, the light falling upon which, and flashing back from it, is sifted in its passage to and fro, and changed from white to emerald-green. Heaps of superficial foam are also formed at intervals along the ledge, and are immediately drawn into long white striæ.[1] Lower down, the surface, shaken by the reaction from below, incessantly rustles into whiteness. The descent finally resolves itself into a rhythm, the water reaching the bottom of the fall in periodic gushes. Nor is the spray uniformly diffused through the air, but is wafted through t in successive veils of gauze-like texture. From all this it is evident that beauty is not absent from the Horseshoe Fall, but majesty is its chief attribute. The plunge of the water is not wild, but deliberate, vast, and fascinating. From the Terrapin Tower, the adjacent arm of the Horseshoe is seen projected against the opposite.one, midway down; to the imagination, therefore, is left the picturing of the gulf into which the cataract plunges.

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[1] The direction of the wind with reference to the course of a ship may be inferred with accuracy from the foam-streaks on the surface of the sea.

The delight which natural scenery produces in some minds is difficult to explain, and the conduct which it prompts can hardly be fairly criticised by those who have never experienced it. It seems to me a deduction from the completeness of the celebrated Thomas Young, that he was unable to appreciate natural scenery. 'He had really,' says Dean Peacock, 'no taste for life in the country; he was one of those who thought that no one who was able to live in London would be content to live elsewhere.' Well, Dr. Young, like Dr. Johnson, had a right to his delights; but I can understand a hesitation to accept them, high as they were, to the exclusion of

> That o'erflowing joy which Nature yields
> To her true lovers.

To all who are of this mind, the strengthening of desire on my part to see and know Niagara Falls, as far as it is possible for them to be seen and known, will be intelligible.

On the first evening of my visit, I met, at the head of Biddle's Stair, the guide to the Cave of the Winds. He was in the prime of manhood—large, well built, firm and pleasant in mouth and eye. My interest in the scene stirred up his, and made him communicative. Turning to a photograph, he described, by reference to it, a feat which he had accomplished some time previously, and which had brought him almost under the green water of the Horseshoe Fall. 'Can you lead me there to-morrow?' I asked. He eyed me enquiringly, weighing, perhaps, the chances of a man of light build, and with grey in his whiskers, in such an undertaking. 'I wish,' I added, 'to see as much of the fall as can be seen, and where you lead I will endeavour to follow.' His scrutiny relaxed into a smile, and he said, 'Very well; I shall be ready for you to-morrow.'

On the morrow, accordingly, I came. In the hut at the head of Biddle's Stair I stripped wholly, and re-dressed according to instructions,—drawing on two pairs of woollen pantaloons, three woollen jackets, two pairs of socks, and a pair of felt shoes. Even if wet, my guide assured me that the clothes would keep me from being chilled; and he was right. A suit and hood of yellow oilcloth covered all. Most laudable precautions were taken by the young assistant who helped to dress me to keep the water out; but his devices broke down immediately when severely tested.

We descended the stair; the handle of a pitchfork doing, in my case, the duty of an alpenstock. At the bottom, the guide enquired whether we should go first to the Cave of the Winds, or to the Horseshoe, remarking that the latter would try us most. I decided on getting the roughest done first, and he turned to the left over the stones. They were sharp and trying. The base of the first portion of the cataract is covered with huge boulders, obviously the ruins of the limestone ledge above. The water does not distribute itself uniformly among these, but seeks for itself channels through which it pours torrentially. We passed some of these with wetted feet, but without difficulty. At length we came to the side of a more formidable current. My guide walked along its edge until he reached its least turbulent portion. Halting, he said, 'This is our greatest difficulty; if we can cross here, we shall get far towards the Horseshoe.'

He waded in. It evidently required all his strength to steady him. The water rose above his loins, and it foamed still higher. He had to search for footing, amid unseen boulders, against which the torrent rose violently. He struggled and swayed, but he struggled successfully, and finally reached the shallower water at the other side. Stretching out his arm, he said to me, 'Now come on.' I looked down the torrent, as it rushed to the river below, which was seething with the tumult of the cataract. De Saussure recommended the inspection of Alpine dangers, with the view of making them familiar to the eye before they are encountered; and it is a wholesome custom in places of difficulty to put the possibility of an accident clearly before the mind, and to decide beforehand what ought to be done should the accident occur. Thus wound up in the present instance, I entered the water. Even where it was not more than knee-deep, its power was manifest. As it rose around me, I sought to split the torrent by presenting a side to it; but the insecurity of the footing enabled it to grasp my loins, twist me fairly round, and bring its impetus to bear upon my back. Further struggle was impossible; and feeling my balance hopelessly gone, I turned, flung myself towards the bank just quitted, and was instantly, as expected, swept into shallower water.

The oilcloth covering was a great incumbrance; it had been made for a much stouter man, and, standing upright after my submersion, my legs occupied the centre of two bags of water. My guide exhorted me to try again. Prudence was at my elbow, whispering dissuasion; but, taking everything into account, it appeared more immoral to retreat than to proceed. Instructed by the first misadventure, I once more entered the stream. Had the alpenstock been of iron it might have helped me; but, as it was, the tendency of the water to sweep it out of my hands rendered it worse than useless. I, however, clung to it by habit. Again the torrent rose, and again I wavered; but, by keeping the left hip well against it, I remained upright, and at length grasped the hand of my leader at the other side. He laughed pleasantly. The first victory was gained, and he enjoyed it. 'No traveller,' he said, 'was ever here before.' Soon afterwards, by trusting to a piece of drift-wood which seemed firm, I was again taken off my feet, but was immediately caught by a protruding rock.

We clambered over the boulders towards the thickest spray, which soon became so weighty as to cause us to stagger under its shock. For the most part nothing could be seen; we were in the midst of bewildering tumult, lashed by the water, which sounded at times like the cracking of innumerable whips. Underneath this was the deep resonant roar of the cataract. I tried to shield my eyes with my hands, and look upwards; but the defence was useless. The guide continued to move on, but at a certain place he halted, and desired me to take shelter in his lee, and observe the cataract. The spray did not come so much from the upper ledge, as from the rebound of the shattered water when it struck the bottom. Hence the eyes could be protected from the blinding shock of the spray, while the line of vision to the upper ledges remained to some extent clear. On looking upwards over the guide's shoulder I could see the water bending over the ledge, while the Terrapin Tower loomed fitfully through the intermittent spray-gusts. We were right under the tower. A little farther on the cataract, after its first plunge, hit a protuberance some way down, and flew from it in a prodigious burst of spray; through this we staggered. We rounded the promontory on which the Terrapin Tower stands, and moved, amid the wildest commotion, along the arm of the Horseshoe, until the boulders failed us, and the cataract fell into the profound gorge of the Niagara River.

Here the guide sheltered me again, and desired me to look up; I did so, and could see, as before, the green gleam of the mighty curve sweeping over the upper ledge, and the fitful plunge of the water, as the spray between us and it alternately gathered and disappeared. An eminent friend of mine often speaks of the mistake of those physicians who regard man's ailments as purely chemical, to be met by chemical remedies only. He contends for the psychological element of cure. By agreeable emotions, he says, nervous currents are liberated which stimulate blood, brain, and viscera. The influence rained from ladies' eyes enables my friend to thrive on dishes which would kill him if eaten alone. A sanative effect of the same order I experienced amid the spray and thunder of Niagara. Quickened by the emotions there aroused, the blood sped exultingly through the arteries, abolishing introspection, clearing the heart of all bitterness, and enabling one to think with tolerance, if not with tenderness, on the most relentless and unreasonable foe. Apart from its scientific value, and purely as a moral agent, the play was worth the candle. My companion knew no more of me than that I enjoyed the wildness; but as I bent in the shelter of his large frame he said, 'I should like to see you attempting to describe all this.' He rightly thought it indescribable. The name of this gallant fellow was Thomas Conroy.

We returned, clambering at intervals up and down, so as to catch glimpses of the most impressive portions of the cataract. We passed under ledges formed by tabular masses of limestone, and through some curious openings formed by the falling together of the summits of the rocks. At length we found ourselves beside our enemy of the morning. Conroy halted for a minute or two, scanning the torrent thoughtfully. I said that, as a guide, he ought to have a rope in such a place; but he retorted that, as no traveller had ever thought of coming there, he did not see the necessity of keeping a rope. He waded in. The struggle to keep himself erect was evident enough; he swayed, but recovered himself again and again. At length he slipped, gave way, did as I had done, threw himself towards the bank, and was swept into the shallows. Standing in the stream near its edge, he stretched his arm towards me. I retained the pitchfork-handle, for it had been useful among the boulders. By wading some way in, the staff could be made to reach him, and I proposed his seizing it. 'If you are sure,' he replied, 'that, in case of giving way, you can maintain your grasp, then I will certainly hold you.' Remarking that he might count on this, I waded in, and stretched the staff to my companion. It was firmly grasped by both of us. Thus helped, though its onset was strong, I moved safely across the torrent. All danger ended here. We afterwards roamed sociably among the torrents and boulders below the Cave of the Winds. The rocks were covered with organic slime, which could not have been walked over with bare feet, but the felt shoes effectually prevented slipping. We reached the cave and entered it, first by a wooden way carried over the boulders, and then along a narrow ledge, to the point eaten deepest into the shale. When the wind is from the south, the falling water, I am told, can be seen tranquilly from this spot; but when we were there, a blinding hurricane of spray was whirled against us. On the evening of the same day, I went behind the water on the Canada side, which, after the experiences of the morning, struck me as an imposture.

Still even this latter is exciting to some nerves. Its effects upon himself is thus vividly described by Mr. Bakewell, jun.: 'On turning a sharp angle of the rock, a sudden gust of wind met us, coming from the hollow between the fall and the rock, which drove the spray directly in our faces, with such force that in an instant we were wet through. When in the midst of this shower-bath the shock took away my breath: I turned back and scrambled over the loose stones to escape the conflict. The guide soon followed, and told me that I had passed the worst part. With that assurance I made a second attempt; but so wild and disordered was my imagination that when I had reached half way I could bear it no longer.'[1]

To complete my knowledge I desired to see the fall from the river below it, and long negotiations were necessary to secure the means of doing so. The only boat fit for the undertaking had been laid up for the winter; but this difficulty, through the kind intervention of Mr. Townsend, was overcome. The main one was to secure oarsmen sufficiently strong and skilful to urge the boat where I wished it to be taken. The son of the owner of the boat, a finely-built young fellow, but only twenty, and therefore not sufficiently hardened, was willing to go; and up the river, it was stated, there lived another man who would do anything with the boat which strength and daring could accomplish. He came. His figure and expression of face certainly indicated extraordinary firmness and power. On Tuesday, November 5, we started, each of us being clad in oilcloth. The elder oarsman at once assumed a tone of authority over his companion, and struck immediately in amid the breakers below the American Fall. He hugged the cross freshets instead of striking out into the smoother water. I asked him why he did so, and he replied that they were directed *outwards*, not *downwards*. The struggle, however, to prevent the bow of the boat from being turned by them, was often very severe.

The spray was in general blinding, but at times it disappeared and yielded noble views of the fall. The edge of the cataract is crimped by indentations which exalt its beauty. Here and there, a little below the highest ledge, a secondary one juts out; the water strikes it and bursts from it in huge protuberant masses of foam and spray. We passed Goat Island, came to the Horseshoe, and worked for a time along the base of it, the boulders over which Conroy and myself had scrambled a few days previously lying between us and the base. A rock was before us, concealed and revealed at intervals, as the waves passed over it. Our leader tried to get above this rock, first on the outside of it. The water, however, was here in violent motion. The men struggled fiercely, the older one ringing out an incessant peal of command and exhortation to the younger. As we were just clearing the rock, the bow came obliquely to the surge; the boat was turned suddenly round and shot with astonishing rapidity down the river. The men returned to the charge, now trying to get up between the half-concealed rock and the boulders to the left. But the torrent set in strongly through this channel. The tugging was quick and violent, but we made little way. At length, seizing a rope, the principal oarsman made a desperate attempt to get upon one of the boulders, hoping to be able to drag the boat through the channel; but it bumped so violently against the rock, that the man flung himself back and relinquished the attempt.

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[1] 'Mag. of Nat. Hist.,' 1830, pp. 121, 122.

We returned along the base of the American Fall, running in and out among the currents which rushed from it laterally into the river. Seen from below the American Fall is certainly exquisitely beautiful, but it is a mere frill of adornment to its nobler neighbour the Horseshoe. At times we took to the river, from the centre of which the Horseshoe Fall appeared especially magnificent. A streak of cloud across the neck of Mont Blanc can double its apparent height, so here the green summit of the cataract shining above the smoke of spray appeared lifted to an extraordinary elevation. Had Hennepin and La Hontan seen the fall from this position, their estimates of the height would have been perfectly excusable.

From a point a little way below the American Fall, a ferry crosses the river, in summer, to the Canadian side. Below the ferry is a suspension bridge for carriages and foot-passengers, and a mile or two lower down is the railway suspension bridge. Between the ferry and the latter the river Niagara flows unruffled; but at the suspension bridge the bed steepens and the river quickens its motion. Lower down the gorge narrows, and the rapidity and turbulence increase. At the place called the 'Whirlpool Rapids' I estimated the width of the river at 300 feet, an estimate confirmed by the dwellers on the spot. When it is remembered that the drainage of nearly half a continent is compressed into this space, the impetuosity of the river's escape through this gorge may be imagined. Had it not been for Mr. Bierstädt, the distinguished photographer of Niagara, I should have quitted the place without seeing these rapids; for this, and for his agreeable company to the spot, I have to thank him. From the edge of the cliff above the rapids, we descended, a little I confess to a climber's disgust, in an 'elevator,' because the effects are best seen from the water level.

Two kinds of motion are here obviously active, a motion of translation and a motion of undulation—the race of the river through its gorge, and the great waves generated by its collision with, and rebound from, the obstacles in its way. In the middle of the river the rush and tossing are most violent; at all events, the impetuous force of the individual waves is here most strikingly displayed. Vast pyramidal heaps leap incessantly from the river, some of them with such energy as to jerk their summits into the air, where they hang suspended as bundles of liquid spherules. The sun shone for a few minutes. At times the wind, coming up the river, searched and sifted the spray, carrying away the lighter drops, and leaving the heavier ones behind. Wafted in the proper direction, rainbows appeared and disappeared fitfully in the lighter mist. In other directions the common gleam of the sunshine from the waves and their shattered crests was exquisitely beautiful. The complexity of the action was still further illustrated by the fact, that in some cases, as if by the exercise of a local explosive force, the drops were shot radially from a particular centre, forming around it a kind of halo.

The first impression, and, indeed, the current explanation of these rapids is, that the central bed of the river is cumbered with large boulders, and that the jostling, tossing, and wild leaping of the water there, are due to its impact against these obstacles. I doubt this explanation. At all events, there is another sufficient reason to be taken into account. Boulders derived from the adjacent cliffs visibly cumber the *sides* of the river. Against these the water rises and sinks rhythmically but violently, large waves being thus produced. On the generation of each wave, there is an immediate compounding of the wave-motion with the river-motion. The ridges, which in still water would proceed in circular curves round the centre of disturbance, cross the river obliquely, and the result is that at the centre waves commingle, which have really been generated at the sides. In the first instance, we had a composition of wave-motion with river-motion; here we have the coalescence of waves with waves. Where crest and furrow cross each other, the motion is annulled; where furrow and furrow cross, the river is ploughed to a greater depth; and where crest and crest aid each other, we have that astonishing leap of the water which breaks the cohesion of the crests, and tosses them shattered into the air. From the water level the cause of the action is not so easily seen; but from the summit of the cliff the lateral generation of the waves, and their propagation to the centre, are perfectly obvious. If this explanation be correct, the phenomena observed at the Whirlpool Rapids form one of the grandest illustrations of the principle of *interference*. The Nile 'cataract,' Mr Huxley informs me, offers more moderate examples of the same action.

At some distance below the Whirlpool Rapids we have the celebrated whirlpool itself. Here the river makes a sudden bend to the north-east, forming nearly a right angle with its previous direction. The water strikes the concave bank with great force, and scoops it incessantly away. A vast basin has been thus formed, in which the sweep of the river prolongs itself in gyratory currents. Bodies and trees which have come over the falls, are stated to circulate here for days without finding the outlet. From various points of the cliffs above, this is curiously hidden. The rush of the river into the whirlpool is obvious enough; and though you imagine the outlet must be visible, if one existed, you cannot find it. Turning, however, round the bend of the precipice to the north-east, the outlet comes into view.

The Niagara season was over; the chatter of sightseers had ceased, and the scene presented itself as one of holy seclusion and beauty. I went down to the river's edge, where the weird loneliness seemed to increase. The basin is enclosed by high and almost precipitous banks —covered, at the time, with russet woods. A kind of mystery attaches itself to gyrating water, due perhaps to the fact that we are to some extent ignorant of the direction of its force. It is said that at certain points of the whirlpool pine-trees are sucked down, to be ejected mysteriously elsewhere. The water is of the brightest emerald-green. The gorge through which it escapes is narrow, and the motion of the river swift though silent. The surface is steeply inclined, but it is perfectly unbroken. There are no lateral waves, no ripples with their breaking bubbles to raise a murmur; while the depth is here too great to allow the inequality of the bed to ruffle the surface. Nothing can be more beautiful than this sloping liquid mirror formed by the Niagara, in sliding from the whirlpool.

The green colour is, I think, correctly accounted for in Fragment VI. In crossing the Atlantic I had frequent opportunities of testing the explanation there given. Looked properly down upon, there are portions of the ocean to which we should hardly ascribe a trace of blue; at the most, a hint of indigo reaches the eye. The water, indeed, is practically *black*, and this is an indication both of its depth and its freedom from mechanically suspended matter. In small thicknesses water is sensibly transparent to all kinds of light; but, as the thickness increases, the rays of low refrangibility are first absorbed, and after them the other rays. Where, therefore, the water is very deep and very pure, *all* the colours are absorbed, and such water ought to appear black, as no light is sent from its interior to the eye. The approximation of the Atlantic Ocean to this condition is an indication of its extreme purity.

Throw a white pebble into such water; as it sinks it becomes greener and greener, and, before it disappears, it reaches a vivid blue-green. Break such a pebble into fragments, each of these will behave like the unbroken mass; grind the pebble to powder, every particle will yield its modicum of green; and if the particles be so fine as to remain suspended in the water, the scattered light will be a uniform green. Hence the greenness of shoal water. You go to bed with the black Atlantic around you.

You rise in the morning, find it a vivid green, and correctly infer that you are crossing the bank of Newfoundland. Such water is found charged with fine matter in a state of mechanical suspension. The light from the bottom may sometimes come into play, but it is not necessary. A storm can render the water muddy. by rendering the particles too numerous and gross. Such a case occurred towards the close of my visit to Niagara. There had been rain and storm in the upper-lake regions, and the quantity of suspended matter brought down quite extinguished the fascinating green of the Horseshoe.

Nothing can be more superb than the green of the Atlantic waves, when the circumstances are favourable to the exhibition of the colour. As long as a wave remains unbroken no colour appears; but when the foam just doubles over the crest, like an Alpine snow-cornice, under the cornice we often see a display of the most exquisite green. It is metallic in its brilliancy. But the foam is necessary to its production. The foam is first illuminated, and it scatters the light in all directions; the light which passes through the higher portion of the wave alone reaches the eye, and gives to that portion its matchless colour. The folding of the wave, producing, as it does, a series of longitudinal protuberances and furrows which act like cylindrical lenses, introduces variations in the intensity of the light, and materially enhances its beauty.

We have now to consider the genesis and proximate destiny of the Falls of Niagara. We may open our way to this subject by a few preliminary remarks upon erosion. Time and intensity are the main factors of geologic change, and they are in a certain sense convertible. A feeble force acting through long periods, and an intense force acting through short ones, may produce approximately the same results. To Dr. Hooker I have been indebted for some specimens of stones, the first examples of which were picked up by Mr. Hackworth on the shores of Lyell's Bay, near Wellington, in New Zealand. They were described by Mr. Travers in the 'Transactions of the New Zealand Institute.' Unacquainted with their origin, you would certainly ascribe their forms to human workmanship. They resemble knives and spear-heads, being apparently chiselled off into facets, with as much attention to symmetry as if a tool, guided by human intelligence, had passed over them. But no human instrument has been brought to bear upon these stones. They have been wrought into their present shape by the wind-blown sand of Lyell's Bay. Two winds are dominant here, and they in succession urged the sand against opposite sides of the stone; every little particle of sand chipped away its infinitesimal bit of stone, and in the end sculptured these singular forms.[1]

The Sphynx of Egypt is nearly covered up by the sand of the desert. The neck of the Sphynx is partly cut across, not, as I am assured by Mr. Huxley, by ordinary weathering, but by the eroding action of the fine sand blown against it. In these cases Nature furnishes us with hints which may be taken advantage of in art; and this action of sand has been recently turned to extraordinary account in the United States. When in Boston, I was taken by Mr. Josiah Quincey to see the action of the *sand-blast*. A kind of hopper containing fine silicious sand was connected with a reservoir of compressed air, the pressure being variable at pleasure. The hopper ended in a long slit, from which the sand was blown. A plate of glass was placed beneath this slit, and caused to pass slowly under it; it came out perfectly depolished, with a bright opalescent glimmer, such as could only be produced by the most careful grinding. Every little particle of sand urged against the glass, having all its energy concentrated on the point of impact, formed there a little pit, the depolished surface consisting of innumerable hollows of this description.

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[1] 'These stones, which have a strong resemblance to works of human art, occur in great abundance, and of various sizes, from half-an-inch to several inches in length. A large number were exhibited showing the various forms, which are those of wedges, knives, arrow-heads, &c., and all with sharp cutting edges.

'Mr. Travers explained that, notwithstanding their artificial appearance, these stones were formed by the cutting action of the wind-driven sand, as it passed to and fro over an exposed boulder-bank. He gave a minute account of the manner in which the varieties of form are produced, and referred to the effect which the erosive action thus indicated would have on railway and other works executed on sandy tracts.

'Dr. Hector stated that although, as a group, the specimens on the table could not well be mistaken for artificial productions, still the forms are so peculiar, and the edges, in a few of them, so perfect, that if they were discovered associated with human works, there is no doubt that they would have been referred to the so-called "stone period."'—*Extracted from the Minutes of the Wellington Philosophical Society*, February 9, 1869.

But this was not all. By protecting certain portions of the surface, and exposing others, figures and tracery of any required form could be etched upon the glass. The figures of open iron-work could be thus copied; while wire-gauze placed over the glass produced a reticulated pattern. But it required no such resisting substance as iron to shelter the glass. The patterns of the finest lace could be thus reproduced; the delicate filaments of the lace itself offering a sufficient protection. All these effects have been obtained with a simple model of the sand-blast devised by my assistant. A fraction of a minute suffices to etch upon glass a rich and beautiful lace pattern. Any yielding substance may be employed to protect the glass. By immediately diffusing the shock of the particle, such substances practically destroy the local erosive power. The hand can bear, without inconvenience, a sand-shower which would pulverise glass. Etchings executed on glass with suitable kinds of ink are accurately worked out by the sand-blast. In fact, within certain limits, the harder the surface, the greater is the concentration of the shock, and the more effectual is the erosion. It is not necessary that the sand should be the harder substance of the two; corundum, for example, is much harder than quartz; still, quartz-sand can not only depolish, but actually blow a hole through a plate of corundum. Nay, glass may be depolished by the impact of fine shot; the grains in this case bruising the glass, before they have time to flatten, and turn their energy into heat.

And here, in passing, we may tie together one or two apparently unrelated facts. Supposing you turn on, at the lower part of a house, a cock which is fed by a pipe from a cistern at the top of the house, the column of water, from the cistern downwards, is set in motion. By turning off the cock, this motion is stopped; and when the turning off is very sudden, the pipe, if not strong, may be burst by the internal impact of the water. By distributing the turning of the cock over half a second of time, the shock and danger of rupture may be entirely avoided. We have here an example of the concentration of energy in *time*. The sand-blast illustrates the concentration of energy in *space*. The action of flint and steel is an illustration of the same principle. The heat required to generate the spark is intense; and the mechanical action, being moderate, must, to produce fire, be in the highest degree concentrated. This concentration is secured by the collision of hard substances. Calc-spar will not supply the place of flint, nor lead the place of steel, in the production of fire by collision. With the softer substances, the *total* heat produced may be greater than with the hard ones, but, to produce the spark, the heat must be intensely *localised*.

But we can go far beyond the mere depolishing of glass; indeed, I have already said that quartz-sand can wear a hole through corundum. This leads me to express my acknowledgments to General Tilghman,[1] who is the inventor of the sand-blast. To his spontaneous kindness I am indebted for some beautiful illustrations of his process. In one thick plate of glass a figure has been worked out to a depth of $\frac{3}{8}$ths of an inch. A second plate, $\frac{7}{8}$ths of an inch thick, is entirely perforated. Through a circular plate of marble, nearly half an inch thick, open work of the most intricate and elaborate description has been executed. It would probably take many days to perform this work by any ordinary process; with the sand-blast it was accomplished in an hour. So much for the strength of the blast; its delicacy is illustrated by a beautiful example of line engraving, etched on glass by means of the blast.[2]

This power of erosion, so strikingly displayed when sand is urged by air, renders us better able to conceive its action when urged by water. The erosive power of a river is vastly augmented by the solid matter carried along with it. Sand or pebbles, caught in a river vortex, can wear away the hardest rock; 'potholes' and deep cylindrical shafts being thus produced. An extraordinary instance of this kind of erosion is to be seen in the Val Tournanche, above the village of this name. The gorge at Handeck has been thus cut out. Such waterfalls were once frequent in the valleys of Switzerland; for hardly any valley is without one or more transverse barriers of resisting material, over which the river flowing through the valley once fell as a cataract. Near Pontresina, in the Engadin, there is such a case; a hard gneiss being there worn away to form a gorge, through which the river from the Morteratsch glacier rushes. The barrier of the Kirchet above Meyringen is also a case in point. Behind it was a lake, derived from the glacier of the Aar, and over the barrier the lake poured its excess of water. Here the rock, being limestone, was in great part dissolved; but added to this we had the action of the sand particles carried along by the water, each of which, as it struck the rock, chipped it away like the particles of the sand-blast. Thus, by solution and mechanical erosion, the great chasm of the Fiensteraarschlucht was formed. It is demonstrable that the water which flows at the bottoms of such deep fissures once flowed at the level of what is now their edges, and tumbled down the lower faces of the barriers. Almost every valley in Switzerland furnishes examples of this kind; the untenable hypothesis of earthquakes, once so readily resorted to in accounting for these gorges, being now for the most part abandoned. To produce the Cañons of Western America, no other cause is needed than the integration of effects individually infinitesimal.

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[1] The absorbent power, if I may use the phrase, exerted by the industrial arts in the United States, is forcibly illustrated by the rapid transfer of men like Mr. Tilghman from the life of the soldier to that of the civilian. General McClellan, now a civil engineer, whom I had the honour of frequently meeting in New York, is a most eminent example of the same kind. At the end of the war, indeed, a million and a half of men were thus drawn, in an astonishingly short time, from military to civil life. It is obvious that a nation with these tendencies can have no desire for war.

[2] The sand-blast will be in operation this year at the Kensington International Exhibition.

And now we come to Niagara. Soon after Europeans had taken possession of the country, the conviction appears to have arisen that the deep channel of the river Niagara below the falls had been excavated by the cataract. In Mr. Bakewell's 'Introduction to Geology,' the prevalence of this belief has been referred to; it is expressed thus by Professor Joseph Henry in the 'Transactions of the Albany Institute:'[1] 'In viewing the position of the falls, and the features of the country round, it is impossible not to be impressed with the idea that this great natural raceway has been formed by the continued action of the irresistible

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[1] Quoted by Bakewell.

Niagara, and that the falls, beginning at Lewiston, have, in the course of ages, worn back the rocky strata to their present site.' The same view is advocated by Sir Charles Lyell, by Mr. Hall, by M. Agassiz, by Professor Ramsay, indeed by most of those who have inspected the place.

A connected image of the origin and progress of the cataract is easily obtained. Walking northward from the village of Niagara Falls by the side of the river, we have to our left the deep and comparatively narrow gorge, through which the Niagara flows. The bounding cliffs of this gorge are from 300 to 350 feet high. We reach the whirlpool, trend to the north-east, and after a little time gradually resume our northward course. Finally, at about seven miles from the present falls, we come to the edge of a declivity, which informs us that we have been hitherto walking on table-land. At some hundreds of feet below us is a comparatively level plain, which stretches to Lake Ontario. The declivity marks the end of the precipitous gorge of the Niagara. Here the river escapes from its steep mural boundaries, and in a widened bed pursues its way to the lake which finally receives its waters.

The fact that in historic times, even within the memory of man, the fall has sensibly receded, prompts the question, How far has this recession gone? At what point did the ledge which thus continually creeps backwards begin its retrograde course? To minds disciplined in such researches the answer has been, and will be—At the precipitous declivity which crossed the Niagara from Lewiston on the American to Queenston on the Canadian side. Over this transverse barrier the united affluents of all the upper lakes once poured their waters, and here the work of erosion began. The dam, moreover, was demonstrably of sufficient height to cause the river above it to submerge Goat Island; and this would perfectly account for the finding by Sir Charles Lyell, Mr. Hall, and others, in the sand and gravel of the island, the same fluviatile shells as are now found in the Niagara River higher up. It would also account for those deposits along the sides of the river, the discovery of which enabled Lyell, Hall, and Ramsay to reduce to demonstration the popular belief that the Niagara once flowed through a shallow valley.

The physics of the problem of excavation, which I made clear to my mind before quitting Niagara, are revealed by a close inspection of the present Horseshoe Fall. We see evidently that the greatest weight of water bends over the very apex of the Horseshoe. In a passage in his excellent chapter on Niagara Falls, Mr. Hall alludes to this fact. Here we have the most copious and the most violent whirling of the shattered liquid; here the most powerful eddies recoil against the shale. From this portion of the fall, indeed, the spray sometimes rises without solution of continuity to the region of clouds, becoming gradually more attenuated, and passing finally through the condition of true cloud into invisible vapour, which is sometimes reprecipitated higher up. All the phenomena point distinctly to the centre of the river as the place of greatest mechanical energy, and from the centre the vigour of the fall gradually dies away towards the sides. The Horseshoe form, with the concavity facing downwards, is an obvious and necessary consequence of this action. Right along the middle of the river the apex of the curve pushes its way backwards, cutting along the centre a deep and comparatively narrow groove, and draining the sides as it passes them.[1] Hence the remarkable discrepancy between the widths of the Niagara above and below the Horseshoe. All along its course, from Lewiston Heights to its present position, the form of the fall was probably that of a horseshoe; for this is merely the expression of the greater depth, and consequently greater excavating power, of the centre of the river. The gorge, moreover, varies in width, as the depth of the centre of the ancient river varied, being narrowest where that depth was greatest.

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[1] In the discourse the excavation of the centre and drainage of the sides action was illustrated by a model devised by my assistant, Mr. John Cottrell.

The vast comparative erosive energy of the Horseshoe Fall comes strikingly into view when it and the American Fall are compared together. The American branch of the upper river is cut at a right angle by the gorge of the Niagara. Here the Horseshoe Fall was the real excavator. It cut the rock, and formed the precipice, over which the American Fall tumbles. But since its formation, the erosive action of the American Fall has been almost nil, while the Horseshoe has cut its way for 500 yards across the end of Goat Island, and is now doubling back to excavate its channel parallel to the length of the island. This point, which impressed me forcibly, has not, I have just learned, escaped the acute observation of Professor Ramsay.[1] The river bends; the Horseshoe immediately accommodates itself to the bending, and will follow implicitly the direction of the deepest water in the upper stream. The flexibility of the gorge, if I may use the term, is determined by the flexibility of the river channel above it. Were the Niagara centre above the fall sinuous, the gorge would obediently follow its sinuosities. Once suggested, no doubt geographers will be able to point out many examples of this action. The Zambesi is thought to present a great difficulty to the erosion theory, because of the sinuosity of the chasm below the Victoria Falls. But, assuming the basalt to be of tolerably uniform texture, had the river been examined before the formation of this sinuous channel, the present zigzag course of the gorge below the fall could, I am persuaded, have been predicted, while the sounding of the present river would enable us to predict the course to be pursued by the erosion in the future.

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[1] His words are: 'Where the body of water is small in the American Fall, the edge has only receded a few yards (where most eroded) during the time that the Canadian Fall has receded from the north corner of Goat Island to the innermost curve of the Horseshoe Fall.'—*Quarterly Journal of Geological Society*, May 1859.

But not only has the Niagara River cut the gorge; it has carried away the chips of its own workshop. The shale, being probably crumbled, is easily carried away. But at the base of the fall we find the huge boulders already described, and by some means or other these are removed down the river. The ice which fills the gorge in winter, and which grapples with the boulders, has been regarded as the transporting agent. Probably it is so to some extent. But erosion acts without ceasing on the abutting points of the boulders, thus withdrawing their support and urging them gradually down the river. Solution also does its portion of the work. That solid matter is carried down is proved by the difference of depth between the Niagara River and Lake Ontario, where the river enters it. The depth falls from 72 feet to 20 feet, in consequence of the deposition of solid matter caused by the diminished motion of the river.[1]

The accompanying highly instructive map has been reduced from one published in Mr. Hall's 'Geology of New York.' It is based on surveys executed in 1842, by Messrs. Gibson and Evershed. The ragged edge of the American Fall north of Goat Island marks the amount of erosion which it has been able to accomplish, while the Horseshoe Fall was cutting its way southward across the end of Goat Island to its present position. The American Fall is 168 feet high, a precipice cut down, not by itself, but by the Horseshoe Fall. The latter in 1842 was 159 feet high, and, as shown by the map, is already turning

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[1] Near the mouth of the gorge at Queenston, the depth, according to the Admiralty Chart, is 180 feet; well within the gorge it is 132 feet.

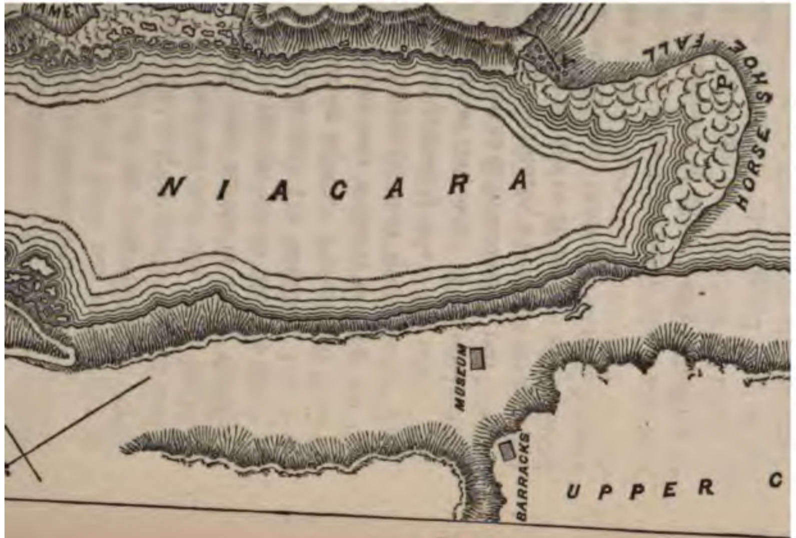

Fig. 6.

eastward, to excavate its gorge along the centre of the upper river. P is the apex of the Horseshoe, and T marks the site of the Terrapin Tower, with the promontory adjacent, round which I was conducted by Conroy. Probably since 1842 the Horseshoe has worked back beyond the position here assigned to it.

In conclusion, we may say a word regarding the proximate future of Niagara. At the rate of excavation assigned to it by Sir Charles Lyell, namely, a foot a year, five thousand years or so will carry the Horseshoe Fall far higher than Goat Island. As the gorge recedes it will drain, as it has hitherto done, the banks right and left of it, thus leaving a nearly level terrace between Goat Island and the edge of the gorge. Higher up it will totally drain the American branch of the river; the channel of which in due time will become cultivable land. The American Fall will then be transformed into a dry precipice, forming a simple continuation of the cliffy boundary of the Niagara. At the place occupied by the fall at this moment we shall have the gorge enclosing a right angle, a second whirlpool being the consequence of this. To those who visit Niagara a few millenniums hence I leave the verification of this prediction. All that can be said is, that if the causes now in action continue to act, it will prove itself literally true.

VIII.

LIFE AND LETTERS OF FARADAY.

1870.

UNDERTAKEN and executed in a reverent and loving spirit, the work of Dr. Bence Jones makes Faraday the virtual writer of his own life. Everybody now knows the story of the philosopher's birth; that his father was a smith; that he was born at Newington Butts in 1791; that he ran along the London pavements, a bright-eyed errand boy, with a load of brown curls upon his head and a packet of newspapers under his arm; that the lad's master was a bookseller and bookbinder—a kindly man, who became attached to the little fellow, and in due time made him his apprentice without fee; that during his apprenticeship he found his appetite for knowledge provoked and strengthened by the books he stitched and covered. Thus he grew in wisdom and stature to his year of legal manhood, when he appears in the volumes before us as a writer of letters, which reveal his occupation, acquirements, and tone of mind. His correspondent was Mr. Abbott, a member of the Society of Friends, who, with a forecast of his correspondent's greatness, preserved his letters and produced them at the proper time.

In later years Faraday always carried in his pocket a blank card, on which he jotted down in pencil his thoughts and memoranda. He made his notes in the laboratory, in the theatre, and in the streets. This distrust of his memory reveals itself in his first letter to Abbott. To a proposition that no new enquiry should be started between them before the old one had been exhaustively discussed, Faraday objects. 'Your notion,' he says, 'I can hardly allow, for the following reason: ideas and thoughts spring up in my mind which are irrevocably lost for want of noting at the time.' Gentle as he seemed, he wished to have his own way, and he had it throughout his life. Differences of opinion sometimes arose between the two friends, and then they resolutely faced each other. 'I accept your offer to fight it out with joy, and shall in the battle of experience cause not pain, but, I hope, pleasure.' Faraday notes his own impetuosity, and incessantly checks it. There is at times something mechanical in his self-restraint. In another nature it would have hardened into mere 'correctness' of conduct; but his overflowing affections prevented this in his case. The habit of self-control became a second nature to him at last, and lent serenity to his later years.

In October 1812 he was engaged by a Mr. De la Roche as a journeyman bookbinder; but the situation did not suit him. His master appears to have been an austere and passionate man, and Faraday was to the last degree sensitive. All his life he continued so. He suffered at times from dejection; and a certain grimness, too, pervaded his moods. 'At present,' he writes to Abbott, 'I am as serious as you can be, and would not scruple to speak a truth to any human being, whatever repugnance it might give rise to. Being in this state of mind, I should have refrained from writing to you, did I not conceive from the general tenor of your letters that your mind is, at proper times, occupied upon serious subjects to the exclusion of those that are frivolous.' Plainly he had fallen into that stern Puritan mood, which not only crucifies the affections and lusts of him who harbours it, but is often a cause of disturbed digestion to his friends.

About three months after his engagement with De la Roche, Faraday quitted him and bookbinding together. He had heard Davy, copied his lectures, and written to him, entreating to be released from Trade, which he hated, and enabled to pursue Science. Davy recognised the merit of his correspondent, kept his eye upon him, and, when occasion offered, drove to his door and sent in a letter, offering him the post of assistant in the laboratory of the Royal Institution. He was engaged March 1, 1812, and on the 8th we find him extracting the sugar from beet-root. He joined the City Philosophical Society which had been founded by Mr. Tatum in 1808. 'The discipline was very sturdy, the remarks very plain, and the results most valuable.' Faraday derived great profit from this little association. In the laboratory he had a discipline sturdier still. Both Davy and himself were at this time frequently cut and bruised by explosions of chloride of nitrogen. One explosion was so rapid 'as to blow my hand open, tear away a part of one nail, and make my fingers so sore that I cannot use them easily.' In another experiment 'the tube and receiver were blown to pieces, I got a cut on the head, and Sir Humphry a bruise on his hand.' And again speaking of the same substance, he says, 'when put in the pump and exhausted, it stood for a moment, and then exploded with a fearful noise. Both Sir H. and I had masks on, but I escaped this time the best. Sir H. had his face cut in two places about the chin, and a violent blow on the forehead struck through a considerable thickness of silk and leather.' It was this same substance that blew out the eye of Dulong.

Over and over again, even at this early date, we can discern the quality which, compounded with his rare intellectual power, made him a great experimental philosopher.

This was his desire to see facts, and not to rest contented with the descriptions of them. He frequently pits the eye against the ear, and affirms the enormous superiority of the organ of vision. Late in life I have heard him say that he could never fully understand an experiment until he had seen it. But he did not confine himself to experiment. He aspired to be a teacher, and reflected and wrote upon the method of scientific exposition. 'A lecturer,' he observes, 'should appear easy and collected, undaunted and unconcerned:' still 'his whole behaviour should evince respect for his audience.' These recommendations were afterwards in great part embodied by himself. I doubt his 'unconcern,' but his fearlessness was often manifested. It used to rise within him as a wave, which carried both him and his audience along with it. On rare occasions also, when he felt himself and his subject hopelessly unintelligible, he suddenly evoked a certain recklessness of thought, and, without halting to extricate his bewildered followers, he would dash alone through the jungle into which he had unwittingly led them; thus saving them from ennui by the exhibition of a vigour which, for the time being, they could neither share nor comprehend.

In October 1813 he quitted England with Sir Humphry and Lady Davy. During his absence he kept a journal, from which copious and interesting extracts have been made by Dr. Bence Jones. Davy was considerate, preferring at times to be his own servant rather than impose on Faraday duties which he disliked. But Lady Davy was the reverse. She treated him as an underling; he chafed under the treatment, and was often on the point of returning home. They halted at Geneva. De la Rive, the elder, had known Davy in 1799, and, by his writings in the 'Bibliothèque Britannique,' had been the first to make the English chemist's labours known abroad. He welcomed Davy to his country residence in 1814. Both were sportsmen, and they often went out shooting together. On these occasions Faraday charged Davy's gun while De la Rive charged his own. Once the Genevese philosopher found himself by the side of Faraday, and in his frank and genial way entered into conversation with the young man. It was evident that a person possessing such a charm of manner and such high intelligence could be no mere servant. On enquiry De la Rive was somewhat shocked to find that the *soi-disant domestique* was really *préparateur* in the laboratory of the Royal Institution; and he immediately proposed that Faraday thenceforth should join the masters instead of the servants at their meals. To this Davy, probably out of weak deference to his wife, objected; but an arrangement was come to that Faraday thenceforward should have his food in his own room. Rumour states that a dinner in honour of Faraday was given by De la Rive. This is a delusion; there was no such banquet; but Faraday never forgot the kindness of the friend who saw his merit when he was a mere *garçon de laboratoire*.[1]

He returned in 1815 to the Royal Institution. Here he helped Davy for years; he worked also for himself, and lectured frequently at the City Philosophical Society. He took lessons in elocution, happily without damage to his natural force, earnestness, and grace of delivery. He was never pledged to theory, and he changed in opinion as knowledge advanced. With him life was growth. In those early lectures we hear him say, 'In knowledge, that man only is to be contemned and despised who is not in a state of transition.' And again: 'Nothing is more difficult and requires more caution than philosophical deduction, nor is there anything more adverse to its accuracy than fixity of opinion.' Not that he was wafted about by every wind of doctrine; but that he united flexibility with his strength. In striking contrast with this intellectual expansiveness was his fixity in religion, but this is a subject which cannot be discussed here.

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[1] While confined last autumn at Geneva by the effects of a fall in the Alps, my friends, with a kindness I can never forget, did all that friendship could suggest to render my captivity pleasant to me. M. de la Rive then wrote out for me the full account, of which the foregoing is a condensed abstract. It was at the desire of Dr. Bence Jones that I asked him to do so. The rumour of a banquet at Geneva illustrates the tendency to substitute for the youth of 1814 the Faraday of later years.

Of all the letters published in these volumes none possess a greater charm than those of Faraday to his wife. Here, as Dr. Bence Jones truly remarks, 'he laid open all his mind and the whole of his character, and what can be made known can scarcely fail to charm every one by its loveliness, its truthfulness, and its earnestness.' Abbott and he sometimes swerved into word-play about love; but up to 1820, or thereabouts, the passion was potential merely. Faraday's journal indeed contains entries which show that he took pleasure in the assertion of his contempt for love; but these very entries became links in his destiny. It was through them that he became acquainted with one who inspired him with a feeling which only ended with his life. His biographer has given us the means of tracing the varying moods which preceded his acceptance. They reveal more than the common alternations of light and gloom; at one moment he wishes that his flesh might melt and he become nothing; at another he is intoxicated with hope. The impetuosity of his character was then unchastened by the discipline to which it was subjected in after-years. The very strength of his passion proved for a time a bar to its advance, suggesting, as it did, to the conscientious mind of Miss Barnard, doubts of her capability to return it with adequate force. But they met again and again, and at each successive meeting he found his heaven clearer, until at length he was able to say, 'Not a moment's alloy of this evening's happiness occurred. Everything was delightful to the last moment of my stay with my companion, because she was so.' The turbulence of doubt subsided, and a calm and elevating confidence took its place. 'What can I call myself,' he writes to her in a subsequent letter, 'to convey most perfectly my affection and love for you? Can I or can truth say more than that for this world I am yours?' Assuredly he made his profession good, and no fairer light falls upon his character than that which reveals his relations to his wife. Never, I believe, existed a manlier, purer, steadier love. Like a burning diamond, it continued to shed, for six-and-forty years, its white and smokeless glow.

Faraday was married on June 12, 1821; and up to this date Davy appears throughout as his friend. Soon afterwards, however, disunion occurred between them, which, while it lasted, must have given Faraday intense pain. It is impossible to doubt the honesty of conviction with which this subject has been treated by Dr. Bence Jones, and there may be facts known to him, but not appearing in these volumes, which justify his opinion that Davy in those days had become jealous of Faraday. This, which is the prevalent belief, is also reproduced in an excellent article in the March number of 'Fraser's Magazine.' But the best analysis I can make of the data fails to present Davy in this light to me. The facts, as I regard them, are briefly these.

In 1820, Oersted of Copenhagen made the celebrated discovery which connects electricity with magnetism, and immediately afterwards the acute mind of Wollaston perceived that a wire carrying a current ought to rotate round its own axis under the influence of a magnetic pole. In 1821 he tried, but failed, to realise this result in the laboratory of the Royal Institution. Faraday was not present at the moment, but he came in immediately afterwards and heard the conversation of Wollaston and Davy about the experiment. He had also heard a rumour of a wager that Dr. Wollaston would eventually succeed.

This was in April. In the autumn of the same year Faraday wrote a history of electro-magnetism, and repeated for himself the experiments which he described. It was while thus instructing himself that he succeeded in causing a wire, carrying an electric current, to rotate round a magnetic pole. This was not the result sought by Wollaston, but it was closely related to that result.

The strong tendency of Faraday's mind to look upon the reciprocal actions of natural forces gave birth to his greatest discoveries; and we, who know this, should be justified in concluding that, even had Wollaston not preceded him, the result would have been the same. But in judging Davy we ought to transport ourselves to his time, and carefully exclude from our thoughts and feelings that noble subsequent life, which would render simply impossible the ascription to Faraday of anything unfair. It would be unjust to Davy to put our knowledge in the place of his, or to credit him with data which he could not have possessed. Rumour and fact had connected the name of Wollaston with these supposed interactions between magnets and currents. When, therefore, Faraday in October published his successful experiment, without any allusion to Wollaston, general, though really ungrounded, criticism followed. I say ungrounded because, firstly, Faraday's experiment was not that of Wollaston, and secondly, Faraday, before he published it, had actually called upon Wollaston, and not finding him at home did not feel himself authorised to mention his name.

In December, Faraday published a second paper on the same subject, from which, through a misapprehension, the name of Wollaston was also omitted. Warburton and others thereupon affirmed that Wollaston's ideas had been

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the mere assistant stage, and become a discoverer. It is now hard to avoid magnifying this error. But had Faraday died or ceased to work at this time, or had his subsequent life been devoted to money-getting, instead of to research, would anybody now dream of ascribing jealousy to Davy? Assuredly not. Why should he be jealous? His reputation at this time was almost without a parallel: his glory was without a cloud. He had added to his other discoveries that of Faraday, and after having been his teacher for seven years, his language to him was this: 'It gives me great pleasure to hear that you are comfortable at the Royal Institution, and I trust that you will not only do something good and honourable for yourself, but also for science.' This is not the language of jealousy, potential or actual. But the chlorine business introduced irritation and anger, to which, and not to any ignobler motive, Davy's opposition to the election of Faraday to the Royal Society is, I am persuaded, to be ascribed.

These matters are touched upon with perfect candour, and becoming consideration, in the volumes of Dr. Bence Jones; but in 'society' they are not always so handled. Here a name of noble intellectual associations is surrounded by injurious rumours which I would willingly scatter for ever. The pupil's magnitude, and the splendour of his position, are too great and absolute to need as a foil the humiliation of his master. Brothers in intellect, Davy and Faraday, however, could never have become brothers in feeling; their characters were too unlike. Davy loved the pomp and circumstance of fame; Faraday the inner consciousness that he had fairly won renown. They were both proud men. But with Davy pride projected itself into the outer world; while with Faraday it became a steadying and dignifying inward force. In one great particular they agreed. Each of them could have turned his science to immense commercial profit, but neither of them such men.

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of pure experimental enquiry, had previously been achieved.

Electricities from various sources were next examined, and their differences and resemblances revealed. He thus assured himself of their substantial identity. He then took up Conduction, and gave many striking illustrations of the influence of Fusion on Conducting Power. Renouncing professional work, from which at this time he might have derived an income of many thousands a year, he poured his whole momentum into his researches. He was long entangled in Electro-chemistry. The light of law was for a time obscured by the thick umbrage of novel facts; but he finally emerged from his researches with the great principle of Definite Electro-chemical Decomposition in his hands. If his discovery of Magneto-electricity may be ranked with that of the Pile by Volta, this new discovery may almost stand beside that of Definite Combining Proportions in Chemistry. He passed on to Static Electricity—its Conduction, Induction, and Mode of Propagation. He discovered and illustrated the principle of Inductive capacity; and, turning to theory, he asked himself how electrical attractions and repulsions are transmitted. Are they, like gravity, actions at a distance, or do they require a medium? If the former, then, like gravity, they will act in straight lines; if the latter, then, like sound or light, they may turn a corner. Faraday held—and his views are gaining ground—that his experiments proved the fact of curvilinear propagation, and hence the operation of a medium. Others denied this; but none can deny the profound and philosophic character of his leading thought.[1] The first volume of the Researches contains all the papers here referred to.

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[1] In a very remarkable paper published in Poggendorff's 'Annalen' for 1857, Werner Siemens accepts and develops Faraday's theory of Molecular Induction.

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he collected and published a fourth
the title, 'Experimental Researc
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power, and magnified his office.

The second volume of the Resea
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The third volume of the Researches opens with a memoir entitled 'The Magnetisation of Light, and the Illumination of Magnetic Lines of Force.' It is difficult even now to affix a definite meaning to this title; but the discovery of the rotation of the plane of polarisation, which it announced, seems pregnant with great results. The writings of William Thomson on the theoretic aspects of the discovery; the excellent electro-dynamic measurements of Wilhelm Weber, which are models of experimental completeness and skill; Weber's labours in conjunction with his lamented friend Kohlrausch—above all, the researches of Clerk Maxwell on the Electro-magnetic Theory of Light—point to that wonderful and mysterious medium, which is the vehicle of light and radiant heat, as the probable basis also of magnetic and electric phenomena. The hope of such a connection was first raised by the discovery here referred to.[1] Faraday himself seemed to cling with particular affection to this discovery. He felt that there was more in it than he was able to unfold. He predicted that it would grow in meaning with the growth of science. This it has done; this it is doing now. Its right interpretation will probably mark an epoch in scientific history.

Rapidly following it is the discovery of Diamagnetism, or the Repulsion of Matter by a magnet. Brugmans had shown that bismuth repelled a magnetic needle. Here he stopped. Le Bailliff proved that antimony did the same.

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[1] A letter addressed to me by Professor Weber on March 18 last contains the following reference to the connection here mentioned: 'Die Hoffnung einer solchen Combination ist durch Faraday's Entdeckung der Drehung der Polarisationsebene durch magnetische Directionskraft zuerst, und sodann durch die Uebereinstimmung derjenigen Geschwindigkeit, welche das Verhältniss der electro-dynamischen Einheit zur electro-statischen ausdrückt, mit der Geschwindigkeit des Lichts angeregt worden; und mir scheint von allen Versuchen, welche zur Verwirklichung dieser Hoffnung gemacht worden sind, das von Herrn Maxwell gemachte am erfolgreichsten.'

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sessed, and which with him were
we should never rise to the lev
His power is that of individual
philosophic method; the energy
ing itself after its own

notice with particular pleasure a letter from Sir John Herschel, in reply to a sealed packet addressed to him by Faraday, but which he had permission to open if he pleased. The packet referred to one of the many unfulfilled hopes which spring up in the mind of fertile investigators:—

'Go on and prosper, "from strength to strength," like a victor marching with assured step to further conquests; and be certain that no voice will join more heartily in the peans that already begin to rise, and will speedily swell into a shout of triumph, astounding even to yourself, than that of J. F. W. Herschel.'

Faraday's behaviour to Melloni in 1835 merits a word of notice. The young man was a political exile in Paris. He had newly fashioned and applied the thermo-electric pile, and had obtained with it results of the greatest importance. But they were not appreciated. With the sickness of disappointed hope Melloni waited for the report of the Commissioners, appointed by the Academy of Sciences to examine his labours. At length he published his researches in the 'Annales de Chimie.' They thus fell into the hands of Faraday, who, discerning at once their extraordinary merit, obtained for their author the Rumford Medal of the Royal Society. A sum of money always accompanies this medal; and the pecuniary help was, at this time, even more essential than the mark of honour to the young refugee. Melloni's gratitude was boundless:—

'Et vous, monsieur,' he writes to Faraday, 'qui appartenez à une société à laquelle je n'avais rien offert, vous qui me connaissiez à peine de nom; vous n'avez pas demandé si j'avais des ennemis faibles ou puissants, ni calculé quel en était le nombre; mais vous avez parlé pour l'opprimé étranger, pour celui qui n'avait pas le moindre droit à tant de bienveillance, et vos paroles ont été accueillies favorablement par des collègues consciencieux! Je reconnais bien là des hommes dignes de leur noble mission, les véritables représentants de la science d'un pays libre et généreux.'

Within the prescribed limits of this article it would be impossible to give even the slenderest summary of Faraday's correspondence, or to carve from it more than the merest fragments of his character. His letters, written to Lord Melbourne and others in 1836, regarding his pension, illustrate his uncompromising independence. The Prime Minister had offended him, but assuredly the apology demanded and given was complete. I think it certain that, notwithstanding the very full account of this transaction given by Dr. Bence Jones, motives and influences were at work which even now are not entirely revealed. The minister was bitterly attacked, but he bore the censure of the press with great dignity. Faraday, while he disavowed having either directly or indirectly furnished the matter of those attacks, did not publicly exonerate his lordship. The Hon. Caroline Fox had proved herself Faraday's ardent friend, and it was she who had healed the breach between the philosopher and the minister. She manifestly thought that Faraday ought to have come forward in Lord Melbourne's defence, and there is a flavour of resentment in one of her letters to him on the subject. No doubt Faraday had good grounds for his reticence, but they are to me unknown.

In 1841 his health broke down utterly, and he went to Switzerland with his wife and brother-in-law. His bodily vigour soon revived, and he accomplished feats of walking respectable even for a trained mountaineer. The published extracts from his Swiss journal contain many beautiful and touching allusions. Amid references to the tints of the Jungfrau, the blue rifts of the glaciers, and the noble Nieson towering over the Lake of Thun, we come upon the charming little scrap which I have elsewhere quoted: 'Clout-nail making goes on here rather considerably, and is a very neat and pretty operation to observe. I love a smith's shop and anything relating to smithery. My father was a smith.' This is from his journal; but he is unconsciously speaking to somebody—perhaps to the world.

His descriptions of the Staubbach, Giessbach, and of the scenic effects of sky and mountain, are all fine and sympathetic. But amid it all, and in reference to it all, he tells his sister that 'true enjoyment is from within, not from without.' In those days Agassiz was living under a slab of gneiss on the glacier of the Aar. Faraday met Forbes at the Grimsel, and arranged with him an excursion to the 'Hôtel des Neufchâtelois;' but indisposition put the project out.

From the Fort of Ham, in 1843, Faraday received a letter addressed to him by Prince Louis Napoleon Bonaparte. He read this letter to me many years ago, and the desire, shown in various ways by the French Emperor, to turn modern science to account, has often reminded me of it since. At the age of thirty-five the prisoner of Ham speaks of 'rendering his captivity less sad by studying the great discoveries' which science owes to Faraday; and he asks a question which reveals his cast of thought at the time: 'What is the most simple combination to give to a voltaic battery, in order to produce a spark capable of setting fire to powder under water or under ground?' Should the necessity arise, the French Emperor will not lack at the outset the best appliances of modern science; while we, I fear, shall have to learn the magnitude of the resources we are now neglecting amid the pangs of actual war.[1]

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[1] The 'science' has since been applied, with astonishing effect, by those who had studied it far more thoroughly than the Emperor of the French.

One turns with renewed pleasure to Faraday's letters to his wife, published in the second volume. Here surely the loving essence of the man appears more distinctly than anywhere else. From the house of Dr. Percy, in Birmingham, he writes thus:—

'Here—even here—the moment I leave the table, I wish I were with you IN QUIET. Oh, what happiness is ours! My runs into the world in this way only serve to make me esteem that happiness the more.'

And again:

'We have been to a grand conversazione in the town-hall, and I have now returned to my room to talk with you, as the pleasantest and happiest thing that I can do. Nothing rests me so much as communion with you. I feel it even now as I write, and catch myself saying the words aloud as I write them.'

Take this, moreover, as indicative of his love for Nature:

'After writing, I walk out in the evening hand in hand with my dear wife to enjoy the sunset; for to me who love scenery, of all that I have seen or can see, there is none surpasses that of heaven. A glorious sunset brings with it a thousand thoughts that delight me.'

Of the numberless lights thrown upon him by the 'Life and Letters,' some fall upon his religion. In a letter to a lady, he describes himself as belonging to 'a very small and despised sect of Christians, known, if known at all, as *Sandemanians*, and our hope is founded on the faith that is in Christ.' He adds: 'I do not think it at all necessary to tie the study of the natural sciences and religion together, and in my intercourse with my fellow-creatures, that which is religious, and that which is philosophical, have ever been two distinct things.' He saw clearly the danger of quitting his moorings, and his science acted indirectly as the safeguard of his particular faith. For his investigations so filled his mind as to leave no room for sceptical questionings, thus shielding from the assaults of philosophy the creed of his youth. His religion was constitutional and hereditary. It was implied in the eddies of his blood and in the tremors of his brain; and, however its outward and visible form might have changed, Faraday would still have possessed its elemental constituents—awe, reverence, truth, and love.

It is worth enquiring how so profoundly religious a mind, and so great a teacher, would be likely to regard our present discussions on the subject of education. Faraday would be a 'secularist' were he now alive. He had no sympathy with those who contemn knowledge unless it be accompanied by dogma. A lecture delivered before the City Philosophical Society in 1818, when he was twenty-six years of age, expresses the views regarding education which he entertained to the end of his life. 'First, then,' he says, 'all theological considerations are banished from the society, and of course from my remarks; and whatever I may say has no reference to a future state, or to the means which are to be adopted in this world in anticipation of it. Next, I have no intention of substituting anything for religion, but I wish to take that part of human nature which is independent of it. Morality, philosophy, commerce, the various institutions and habits of society, are independent of religion, and may exist either with or without it. They are always the same, and can dwell alike in the breasts of those who, from opinion, are entirely opposed in the set of principles they include in the term religion, or in those who have none.

'To discriminate more closely, if possible, I will observe that we have *no* right to judge religious opinions; but the human nature of this evening is that part of man which we *have* a right to judge. And I think it will be found, on examination, that this humanity—as it may perhaps be called—will accord with what I have before described as being in our own hands so improvable and perfectible.'

Among my old papers I find the following remarks on one of my earliest dinners with Faraday: 'At two o'clock he came down for me. He, his niece, and myself, formed the party. "I never give dinners," he said. "I don't know how to give dinners, and I never dine out. But I should not like my friends to attribute this to a wrong cause. I act thus for the sake of securing time for work, and not through religious motives, as some imagine." He said grace. I am almost ashamed to call his prayer a "saying of grace." In the language of Scripture, it might be described as the petition of a son, into whose heart God had sent the Spirit of His Son, and who with absolute trust asked a blessing from his father. We dined on roast beef, Yorkshire pudding, and potatoes; drank sherry, talked of research and its requirements, and of his habit of keeping himself free from the distractions of society. He was bright and joyful—boylike, in fact, though he is now sixty-two. His work excites admiration, but contact with him warms and elevates the heart. Here, surely, is a strong man. I love strength; but let me not forget the example of its union with modesty, tenderness, and sweetness, in the character of Faraday.'

Faraday's progress in discovery, and the salient points of his character, are well brought out by the wise choice of letters and extracts published in these volumes. I will not call the labours of the biographer final. So great a character will challenge reconstruction. In the coming time some sympathetic spirit, with the requisite strength, knowledge, and solvent power, will, I doubt not, render these materials plastic, give them more perfect organic form, and send through them, with less of interruption, the currents of Faraday's life. 'He was too good a man,' writes his present biographer, 'for me to estimate rightly, and too great a philosopher for me to understand thoroughly.' That may be: but the reverent affection to which we owe the discovery, selection, and arrangement of the materials here placed before us, is probably a surer guide than mere literary skill. The task of the artist who may wish in future times to reproduce the real though unobtrusive grandeur, the purity, beauty, and childlike simplicity of him whom we have lost, will find his chief treasury already provided for him by Dr. Bence Jones's labour of love.

IX.

THE COPLEY MEDALIST OF 1870.

THIRTY years ago Electro-magnetism was looked to as a motive power, which might possibly compete with steam. In centres of industry, such as Manchester, attempts to investigate and apply this power were numerous. This is shown by the scientific literature of the time. Among others Mr. James Prescot Joule, a resident of Manchester, took up the subject, and, in a series of papers published in Sturgeon's 'Annals of Electricity' between 1839 and 1841, described various attempts at the construction and perfection of electro-magnetic engines. The spirit in which Mr. Joule pursued these enquiries is revealed in the following extract: 'I am particularly anxious,' he says, 'to communicate any new arrangement in order, if possible, to forestall the monopolising designs of those who seem to regard this most interesting subject merely in the light of pecuniary speculation.' He was naturally led to investigate the laws of electro-magnetic attractions, and in 1840 he announced the important principle that the attractive force exerted by two electro-magnets, or by an electro-magnet and a mass of annealed iron, is directly proportional to the square of the strength of the magnetising current; while the attraction exerted between an electro-magnet and the pole of a permanent steel magnet, varies simply as the strength of the current. These investigations were conducted independently of, though a little subsequently to, the celebrated enquiries of Henry, Jacobi, and Lenz and Jacobi, on the same subject.

On December 17, 1840, Mr. Joule communicated to the Royal Society a paper on the production of heat by Voltaic electricity. In it he announced the law that the calorific effects of equal quantities of transmitted electricity are proportional to the resistance overcome by the current, whatever may be the length, thickness, shape, or character of the metal which closes the circuit; and also proportional to the square of the quantity of transmitted electricity. This is a law of primary importance. In another paper, presented to, but declined by, the Royal Society, he confirmed this law by new experiments, and materially extended it. He also executed experiments on the heat consequent on the passage of Voltaic electricity through electrolytes, and found, in all cases, that the heat evolved by the proper action of any Voltaic current is proportional to the square of the intensity of that current, multiplied by the resistance to conduction which it experiences. From this law he deduced a number of conclusions of the highest importance to electro-chemistry.

It was during these enquiries, which are marked throughout by rare sagacity and originality, that the great idea of establishing quantitative relations between Mechanical Energy and Heat arose and assumed definite form in his mind. In 1843 Mr. Joule read before the meeting of the British Association at Cork a paper 'On the Calorific Effects of Magneto-Electricity, and on the Mechanical Value of Heat.' Even at the present day this memoir is tough reading, and at the time it was written it must have appeared hopelessly entangled. This, I should think, was the reason why Faraday advised Mr. Joule not to submit the paper to the Royal Society. But its drift and results are summed up in these memorable words by its author, written some time subsequently: 'In that paper it was demonstrated experimentally, that the mechanical power exerted in turning a magneto-electric machine is converted into the heat evolved by the passage of the currents of induction through its coils; and, on the other hand, that the motive power of the electro-magnetic engine is obtained at the expense of the heat, due to the chemical reaction of the battery by which it is worked.'[1] It is needless to dwell upon the weight and importance of this statement.

Considering the imperfections incidental to a first determination, it is not surprising that the 'mechanical values of heat,' deduced from the different series of experiments published in 1843, varied widely from each other. The lowest limit was 587, and the highest 1,026 foot-pounds, for 1° Fahr. of temperature.

One noteworthy result of his enquiries, which was pointed out at the time by Mr. Joule, had reference to the exceedingly small fraction of the heat actually converted into useful effect in the steam-engine. The thoughts of the celebrated Julius Robert Mayer, who was then engaged in Germany upon the same question, had moved independently in the same groove; but to his labours due reference will be made on a future occasion.[2] In the memoir now referred to, Mr. Joule also announced that he had proved heat to be evolved during the passage of water through narrow tubes; and he deduced from these experiments an equivalent of 770 foot-pounds, a figure remarkably near the one now accepted. A detached statement regarding the origin and convertibility of animal heat strikingly illustrates the penetration of Mr. Joule, and his mastery of principles, at the period now referred to. A friend had mentioned to him Haller's hypothesis, that animal heat might arise from the friction of the blood in the veins and arteries. 'It is unquestionable,' writes Mr. Joule, 'that heat is produced by such friction; but it must be understood that the mechanical force expended in the friction is a part of the force of affinity which causes the venous blood to unite with oxygen, so that the whole heat of the system must still be referred to the chemical changes. But if the animal were engaged in turning a piece of machinery, or in ascending a mountain, I apprehend that in proportion to the muscular effort put forth for the purpose, a *diminution* of the heat evolved in the system by a given chemical action would be experienced.' The italics in this memorable passage, written, it is to be remembered, in 1843, are Mr. Joule's own.

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[1] Phil. Mag. May, 1845.

[2] See the next Fragment.

The concluding paragraph of this British Association paper equally illustrates his insight and precision, regarding the nature of chemical and latent heat. 'I had,' he writes, 'endeavoured to prove that when two atoms combine together, the heat evolved is exactly that which would have been evolved by the electrical current due to the chemical action taking place, and is therefore proportional to the intensity of the chemical force causing the atoms to combine. I now venture to state more explicitly, that it is not precisely the attraction of affinity, but rather the mechanical force expended by the atoms in falling towards one another, which determines the intensity of the current, and, consequently, the quantity of heat evolved; so that we have a simple hypothesis by which we may explain why heat is evolved so freely in the combination of gases, and by which indeed we may account "latent heat" as a mechanical power, prepared for action, as a watch-spring is when wound up. Suppose, for the sake of illustration, that 8 lbs. of oxygen and 1 lb. of hydrogen were presented to one another in the weight of about 50,000,000 lbs. raised foot. Now if the oxygen and hydroge to each other in a liquid state, the h would be less than before, because t bining would fall through less space.' are needed to point out the command cular physics, in their relation to the m heat, implied by this statement.

Perfectly assured of the importanc which his experiments aimed at estab did not rest content with results prese pancies as those above referred to. He to entirely new methods, and made elab on the thermal changes produced in air sion: firstly, against a pressure, and the work; secondly, against no pressure, a forming no work. He thus established between the heat consumed and the w five different series of experiments different mechanical equivalents; the a them being far greater than that att experiments. The mean of them was From experiments with water agitated b he deduced, in 1845, an equivalent of made Mr. Joule completely master of the conditions essential to accuracy and success. Bringing his ripened experience to bear upon the subject, he executed in 1849 a series of 40 experiments on the friction of water, 50 experiments on the friction of mercury, and 20 experiments on the friction of plates of cast-iron. He deduced from these experiments our present mechanical equivalent of heat, justly recognised all over the world as 'Joule's equivalent.'

There are labours so great and so pregnant in consequences, that they are most highly praised when they are most simply stated. Such are the labours of Mr. Joule. They constitute the experimental foundation of a principle of incalculable moment, not only to the practice, but still more to the philosophy of Science. Since the days of Newton, nothing more important than the theory, of which Mr. Joule is the experimental demonstrator, has been enunciated.

I have omitted all reference to the numerous minor papers with which Mr. Joule has enriched scientific literature. Nor have I alluded to the important investigations which he has conducted jointly with Sir William Thomson. But sufficient, I think, has been here said to show that, in conferring upon Mr. Joule the highest honour of the Royal Society, the Council paid to genius not only a well-won tribute, but one which had been fairly earned twenty years previously.

X.

THE COPLEY MEDALIST OF 1871.

DR. JULIUS ROBERT MAYER was educated for the medical profession. In the summer of 1840, as he himself informs us, he was at Java, and there observed that the venous blood of some of his patients had a singularly bright red colour. The observation riveted his attention; he reasoned upon it, and came to the conclusion that the brightness of the colour was due to the fact that a less amount of oxidation sufficed to keep up the temperature of the body in a hot climate than in a cold one. The darkness of the venous blood he regarded as the visible sign of the energy of the oxidation.

It would be trivial to remark that accidents such as this, appealing to minds prepared for them, have often led to great discoveries. Mayer's attention was thereby drawn to the whole question of animal heat. Lavoisier had ascribed this heat to the oxidation of the food. 'One great principle,' says Mayer, 'of the physiological theory of combustion, is that under all circumstances the same amount of fuel yields, by its perfect combustion, the same amount of heat; that this law holds good even for vital processes; and that hence the living body, notwithstanding all its enigmas and wonders, is incompetent to generate heat out of nothing.'

But beyond the power of generating internal heat, the animal organism can also generate heat outside of itself.

A blacksmith, for example, by hammering can heat a nail, and a savage by friction can warm wood to its point of ignition. Now, unless we give up the physiological axiom that the living body cannot create heat out of nothing, 'we are driven,' says Mayer, 'to the conclusion that it is the *total* heat generated within and *without* that is to be regarded as the true calorific effect of the matter oxidised in the body.'

From this, again, he inferred that the heat generated externally must stand in a fixed relation to the work expended in its production. For, supposing the organic processes to remain the same; if it were possible, by the mere alteration of the apparatus, to generate different amounts of heat by the same amount of work, it would follow that the oxidation of the same amount of material would sometimes yield a less, sometimes a greater, quantity of heat. 'Hence,' says Mayer, 'that a fixed relation subsists between heat and work, is a postulate of the physiological theory of combustion.'

This is the simple and natural account, given subsequently by Mayer himself, of the course of thought started by his observation in Java. But the conviction once formed, that an unalterable relation subsists between work and heat, it was inevitable that Mayer should seek to express it numerically. It was also inevitable that a mind like his, having raised itself to clearness on this important point, should push forward to consider the relationship of natural forces generally. At the beginning of 1842 his work had made considerable progress; but he had become physician to the town of Heilbronn, and the duties of his profession limited the time which he could devote to purely scientific enquiry. He thought it wise, therefore, to secure himself against accident, and in the spring of 1842 wrote to Liebig, asking him to publish in his 'Annalen' a brief preliminary notice of the work then accomplished. Liebig did so, and Dr. Mayer's first paper is contained in the May number of the 'Annalen' for 1842.

Mayer had reached his conclusions by reflecting on the complex processes of the living body; but his first step in public was to state definitely the physical principles on which his physiological deductions were to rest. He begins, therefore, with the forces of inorganic nature. He finds in the universe two systems of causes which are not mutually convertible;—the different kinds of matter and the different forms of force. The first quality of both he affirms to be *indestructibility*. A force cannot become nothing, nor can it arise from nothing. Forces are convertible but not destructible. In the terminology of his time, he then gives clear expression to the ideas of potential and dynamic energy, illustrating his point by a weight resting upon the earth, suspended at a height above the earth, and actually falling to the earth. He next fixes his attention on cases where motion is apparently destroyed, without producing other motion; on the shock of inelastic bodies, for example. Under what form does the vanished motion maintain itself? Experiment alone, says Mayer, can help us here. He warms water by stirring it; he refers to the force expended in overcoming friction. Motion in both cases disappears; but heat is generated, and the quantity generated is the equivalent of the motion destroyed. 'Our locomotives,' he observes with extraordinary sagacity, 'may be compared to distilling apparatus: the heat beneath the boiler passes into the motion of the train, and is again deposited as heat in the axles and wheels.'

A numerical solution of the relation between heat and work was what Mayer aimed at, and towards the end of his first paper he makes the attempt. It was known that a definite amount of air, in rising one degree in temperature, can take up two different amounts of heat. If its volume be kept constant, it takes up one amount: if its pressure be kept constant it takes up a different amount. These two amounts are called the specific heat under constant volume and under constant pressure. The ratio of the first to the second is as 1 : 1·421. No man, to my knowledge, prior to Dr. Mayer, penetrated the significance of these two numbers. He first saw that the excess 0·421 was not, as then universally supposed, heat actually lodged in the gas, but heat which had been actually consumed by the gas in expanding against pressure. The amount of work here performed was accurately known, the amount of heat consumed was also accurately known, and from these data Mayer determined the mechanical equivalent of heat. Even in this first paper he is able to direct attention to the enormous discrepancy between the theoretic power of the fuel consumed in steam-engines, and their useful effect.

Though this paper contains but the germ of his further labours, I think it may be safely assumed that, as regards the mechanical theory of heat, this obscure Heilbronn physician, in the year 1842, was in advance of all the scientific men of the time.

Having, by the publication of this paper, secured himself against what he calls 'Eventualitäten,' he devoted every hour of his spare time to his studies, and in 1845 published a memoir which far transcends his first one in weight and fulness, and, indeed, marks an epoch in the history of science. The title of Mayer's first paper was, 'Remarks on the Forces of Inorganic Nature.' The title of his second great essay was, 'Organic Motion in its Connection with Nutrition.' In it he expands and illustrates the physical principles laid down in his first brief paper. He goes fully through the calculation of the mechanical equivalent of heat. He calculates the performances of steam-engines, and finds that 100 lbs. of coal, in a good working engine, produce only the same amount of heat as 95 lbs. in an unworking one; the 5 lbs. disappearing having been converted into work. He determines the useful effect of gunpowder, and finds nine per cent. of the force of the consumed charcoal invested on the moving ball. He records observations on the heat generated in water agitated by the pulping-engine of a paper manufactory, and calculates the equivalent of that heat in horse-power. He compares chemical combination with mechanical combination—the union of atoms with the union of falling bodies with the earth. He calculates the velocity with which a body starting at an infinite distance would strike the earth's surface, and finds that the heat generated by its collision would raise an equal weight of water 17,356° C. in temperature. He then determines the thermal effect which would be produced by the earth itself falling into the sun. So that here, in 1845, we have the germ of that meteoric theory of the sun's heat which Mayer developed with such extraordinary ability three years afterwards. He also points to the almost exclusive efficacy of the sun's heat in producing mechanical motions upon the earth, winding up with the profound remark, that the heat developed by friction in the wheels of our wind and water mills comes from the sun in the form of vibratory motion; while the heat produced by mills driven by tidal action is generated at the expense of the earth's axial rotation.

Having thus, with firm step, passed through the powers of inorganic nature, his next object is to bring his principles to bear upon the phenomena of vegetable and animal life. Wood and coal can burn; whence come their heat, and the work producible by that heat? From the immeasurable reservoir of the sun. Nature has proposed to herself the task of storing up the light which streams earthward from the sun, and of casting into a permanent form the most fugitive of all powers. To this end she has overspread the earth with organisms which, while living, take in the solar light, and by its consumption generate forces of another kind. These organisms are plants. The vegetable world, indeed, constitutes the instrument whereby the wave-motion of the sun is changed into the rigid form of chemical tension, and thus prepared for future use. With this prevision, as shall subsequently be shown, the existence of the human race itself is inseparably connected. It is to be observed that Mayer's utterances are far from being anticipated by vague statements regarding the 'stimulus' of light, or regarding coal as 'bottled sunlight.' He first saw the full meaning of De Saussure's observation of the reducing power of the solar rays, and gave that observation its proper place in the doctrine of conservation. In the leaves of a tree, the carbon and oxygen of carbonic acid, and the hydrogen and oxygen of water, are forced asunder at the expense of the sun, and the amount of power thus sacrificed is accurately restored by the combustion of the tree. The heat and work potential in our coal strata are so much strength withdrawn from the sun of former ages. Mayer lays the axe to the root of many notions regarding 'vital force' which were prevalent when he wrote. With the plain fact before us that plants cannot perform the work of reduction, or generate chemical tensions, in the absence of the solar rays, it is, he contends, incredible that these tensions should be caused by the mystic play of the vital force. Such an hypothesis would cut off all investigation; it would land us in a chaos of unbridled phantasy. 'I count,' he says, 'therefore, upon assent when I state, as an axiomatic truth, that during vital processes the *conversion* only, and never the *creation* of matter or force occurs.'

Having cleared his way through the vegetable world, as he had previously done through inorganic nature, Mayer passes on to the other organic kingdom. The physical forces collected by plants become the property of animals. Animals consume vegetables, and cause them to reunite with the atmospheric oxygen. Animal heat is thus produced; and not only animal heat, but animal motion. There is no indistinctness about Mayer here; he grasps his subject in all its details, and reduces to figures the concomitants of muscular action. A bowler who imparts to an 8-lb. ball a velocity of 30 feet, consumes in the act $\frac{1}{10}$ of a grain of carbon. A man weighing 150 lbs., who lifts his own body to a height of 8 feet, consumes in the act 1 grain of carbon. In climbing a mountain 10,000 feet high, the consumption of the same man would be 2 oz. 4 drs. 50 grs. of carbon. Boussingault had determined experimentally the addition to be made to the food of horses when actively working, and Liebig had determined the addition to be made in the case of men. Employing the mechanical equivalent of heat, which he had previously calculated, Mayer proves the additional food to be amply sufficient to cover the increased oxidation.

But he does not content himself with showing, in a general way, that the human body burns according to definite laws, when it performs mechanical work. He seeks to determine the particular portion of the body consumed, and in doing so executes some noteworthy calculations. The muscles of a labourer 150 lbs. in weight weigh 64 lbs.; when perfectly desiccated they fall to 15 lbs. Were the oxidation corresponding to that labourer's work exerted on the muscles alone, they would be utterly consumed in 80 days. The heart furnishes a still more striking example. Were the oxidation necessary to sustain the heart's action exerted upon its own tissue, it would be utterly consumed in 8 days. And if we confine our attention to the two ventricles, their action would be sufficient to consume the associated muscular tissue in 3½ days. Here, in his own words, emphasised in his own way, is Mayer's pregnant conclusion from these calculations: 'The muscle is only the apparatus by means of which the conversion of the force is effected; *but it is not the substance consumed in the production of the mechanical effect.*' He calls the blood 'the oil of the lamp of life;' it is the slow-burning fluid whose chemical force, in the furnace of the capillaries, is sacrificed to produce animal motion. This was Mayer's conclusion twenty-six years ago. It was in complete opposition to the scientific conclusions of his time; but eminent investigators have since amply verified it.

Thus, in baldest outline, I have sought to give some notion of the first half of this marvellous essay. The second half is so exclusively physiological that I do not wish to meddle with it. I will only add the illustration employed by Mayer to explain the action of the nerves upon the muscles. As an engineer, by the motion of his finger in opening a valve or loosing a detent, can liberate an amount of mechanical motion almost infinite compared with its exciting cause, so the nerves, acting upon the muscles, can unlock an amount of activity, wholly out of proportion to the work done by the nerves themselves.

As regards these questions of weightiest import to the science of physiology, Dr. Mayer, in 1845, was assuredly far in advance of all living men.

Mayer grasped the mechanical theory of heat with commanding power, illustrating it and applying it in the most diverse domains. He began, as we have seen, with physical principles; he determined the numerical relation between heat and work; he revealed the source of the energies of the vegetable world, and showed the relationship of the heat of our fires to solar heat. He followed the energies which were potential in the vegetable, up to their local exhaustion in the animal. But in 1845 a new thought was forced upon him by his calculations. He then, for the first time, drew attention to the astounding amount of heat generated by gravity where the force has sufficient distance to act through. He proved, as I have before stated, the heat of collision of a body falling from an infinite distance to the earth, to be sufficient to raise the temperature of a quantity of water, equal to the falling body in weight, 17,356° C. He also found, in 1845, that the gravitating force between the earth and sun was competent to generate an amount of heat equal to that obtainable from the combustion of 6,000 times the weight of the earth of solid coal. With the quickness of genius he saw that we had here a power sufficient to produce the enormous temperature of the sun, and also to account for the primal molten condition of our own planet. Mayer shows the utter inadequacy of chemical forces, as we know them, to produce or maintain the solar temperature. He shows that were the sun a lump of coal it would be utterly consumed in 5,000 years. He shows the difficulties attending the assumption that the sun is a cooling body; for, supposing it to possess even the high specific heat of water, its temperature would fall 15,000° in 5,000 years. He finally concludes that the light and heat of the sun are maintained by the constant impact of meteoric matter. I never ventured an opinion as to the accuracy of this theory; that is a question which may still have to be fought out. But I refer to it as an illustration of the force of genius, with which Mayer followed the mechanical theory of heat through all its applications. Whether the meteoric theory be a matter of fact or not, with him abides the honour of proving to demonstration that the light and heat of suns and stars *may* be originated and maintained by the collisions of cold planetary matter.

It is the man who with the scantiest data could accomplish all this in six short years, and in the hours snatched from the duties of an arduous profession, that the Royal Society, in 1871, crowned with its highest honour. Dr. Mayer had never previously received any mark of recognition from the Society.

Comparing this brief history with that of the Copley Medalist of 1870, the differentiating influence of 'environment,' on two minds of similar natural cast and endowment, comes out in an instructive manner. Withdrawn from mechanical appliances, Mayer fell back upon reflection, selecting with marvellous sagacity, from existing physical data, the single result on which could be founded a calculation of the mechanical equivalent of heat. In the midst of mechanical appliances, Joule resorted to experiment, and laid the broad and firm foundation which has secured for the mechanical theory the acceptance it now enjoys. A great portion of Joule's time was occupied in actual manipulation; freed from this, Mayer had time to follow the theory into its most abtruse and impressive applications. With their places reversed, however, Joule might have become Mayer, and Mayer might have become Joule.

It does not lie in the way of these brief articles to enter upon the great developments of the Dynamical Theory, accomplished since Joule and Mayer executed their memorable labours.

XI.

ELEMENTARY MAGNETISM.

A LECTURE TO SCHOOLMASTERS.

WE have no reason to believe that the sheep or the dog, or indeed any of the lower animals, feel an interest in the laws by which natural phenomena are regulated. A herd may be terrified by a thunder-storm; birds may go to roost, and cattle return to their stalls, during a solar eclipse; but neither birds nor cattle, as far as we know, ever think of enquiring into the causes of these things. It is otherwise with man. The presence of natural objects, the occurrence of natural events, the varied appearances of the universe in which he dwells, penetrate beyond his organs of sense, and appeal to an inner power of which the senses are the mere instruments and excitants. No fact is to him either final or original. He cannot limit himself to the contemplation of it alone, but endeavours to ascertain its position in a series to which the constitution of his mind assures him it must belong. He regards all that he witnesses in the present as the efflux and sequence of something that has gone before, and as the source of a system of events which is to follow. The notion of spontaneity, by which in his ruder state he accounted for natural events, is abandoned; the idea that nature is an aggregate of independent parts also disappears, as the connection and mutual dependence of physical powers become more and more manifest: until he is finally led, and that chiefly by the science of which I happen this evening to be the exponent, to regard Nature as an organic whole—as a body each of whose members sympathises with the rest, changing, it is true, from age to age, but without one real break of continuity, or a single interruption of the fixed relation of cause and effect.

The system of things which we call Nature is, however, too vast and various to be studied first-hand by any single mind. As knowledge extends there is always a tendency to subdivide the field of investigation. Its various parts are taken up by different individuals, and thus receive a greater amount of attention than could possibly be bestowed on them if each investigator aimed at the mastery of the whole. East, west, north, and south, the human mind pushes its conquests; but the centrifugal form in which knowledge, as a whole, advances, spreading ever wider on all sides, is due in reality to the exertions of individuals, each of whom directs his efforts, more or less, along a single line. Accepting, in many respects, his culture from his fellow-men—taking it from spoken words and from written books, in some one direction, the student of Nature must actually touch his work. He may otherwise be a distributor of knowledge, but not a creator, and he fails to attain that vitality of thought, and correctness of judgment, which direct and habitual contact with natural truth can alone impart.

One large department of the system of Nature which forms the chief subject of my own studies, and to which it is my duty to call your attention this evening, is that of physics, or natural philosophy. This term is large enough to cover the study of Nature generally, but it is usually restricted to a department which, perhaps, lies closer to our perceptions than any other. It deals with the phenomena and laws of light and heat—with the phenomena and laws of magnetism and electricity—with those of sound—with the pressures and motions of liquids and gases, whether in a state of translation or of undulation. The science of mechanics is a portion of natural philosophy, though at present so large as to need the exclusive attention of him who would cultivate it profoundly. Astronomy is the application of physics to the motions of the heavenly bodies, the vastness of the field causing it, however, to be regarded as a department in itself. In chemistry physical agents play important parts. By heat and light we cause bodies to combine, and by heat and light we decompose them. Electricity tears asunder the locked atoms of compounds. Through their power of separating carbonic acid into its constituents, the solar beams build up the whole vegetable world, and by it the animal world. The touch of the self-same beams causes hydrogen and chlorine to unite with sudden explosion, and to form by their combination a powerful acid. Thus physics and chemistry intermingle. Physical agents are, however, employed by the chemist as a means to an end; while in physics proper the laws and phenomena of the agents themselves, both qualitative and quantitative, are the primary objects of attention.

My duty here to-night is to spend an hour in telling how the subject of magnetism is to be studied, and how a knowledge of it is to be imparted to others. When first invited to do this, I hesitated before accepting the responsibility. It would be easy to entertain you with an account of what natural philosophy has accomplished. I might point to those applications of science regarding which we hear so much in the newspapers, and which we often find mistaken for science itself. I might, of course, ring changes on the steam-engine and the telegraph, the electrotype and the photograph, the medical applications of physics, and the million other inlets by which scientific thought filters into practical life. That would be easy compared with the task of informing you how you are to make the study of physics the instrument of your own culture; how you are to possess its facts and make them living seeds which shall take root and grow in the mind, and not lie like dead lumber in the storehouse of memory. This is a task much heavier than the mere cataloguing of scientific achievements; and it is one which, feeling my own want of time and power to execute it aright, I might well hesitate to accept.

But let me sink excuses, and attack the work to the best of my ability. First and foremost, then, I would advise you to get a knowledge of facts from actual observation. Facts looked at directly are vital; when they pass into words half the sap is taken out of them. You wish, for example, to get a knowledge of magnetism; well, provide yourself with a good book on the subject, if you can, but do not be content with what the book tells you; do not be satisfied with its descriptive woodcuts; see the operation of the force yourself. Half of our book writers describe experiments which they never made, and their descriptions often lack both force and truth; but, no matter how clever or conscientious they may be, their written words cannot supply the place of actual observation. Every fact has numerous radiations, which are shorn off by the man who describes it. Go, then, to a philosophical instrument maker, and give, according to your means, for a straight bar-magnet, say, half-a-crown, or, if you can afford it, five shillings for a pair of them; or get a smith to cut a length of ten inches from a bar of steel an inch wide and half an inch thick; file its ends decently, harden it, and get somebody like myself to magnetise it. Two bar-magnets are better than one. Procure some darning-needles such as these. Provide yourself also with a little unspun silk, which will give you a suspending fibre void of torsion; make a little loop of paper, or of wire, and attach your fibre to it. Do it neatly. In the loop place your darning-needle, and bring the two ends or poles, as they are called, of your magnet successively up to either end of the needle. Both the poles, you find, attract both ends of the needle. Replace the needle by a bit of annealed iron wire; the same effects ensue. Suspend successively little rods of lead, copper, silver, or brass, of wood, glass, ivory, or whalebone; the magnet produces no sensible effect upon any of these substances. You thence infer a special property in the case of steel and iron. Multiply your experiments, however, and you will find that some other substances, besides iron, are acted upon by your magnet. A rod of the metal nickel, or of the metal cobalt, from which the blue colour used by painters is derived, exhibits powers similar to those observed with the iron and steel.

In studying the character of the force you may, however, confine yourself to iron and steel, which are always at hand. Make your experiments with the darning-needle over and over again; operate on both ends of the needle; try both ends of the magnet. Do not think the work stupid; you are conversing with Nature, and must acquire a certain grace and mastery over her language; and these practice can alone impart. Let every movement be made with care, and avoid slovenliness from the outset. In every one of your experiments endeavour to feel the responsibility of a moral agent. Experiment, as I have said, is the language by which we address Nature, and through which she sends her replies; in the use of this language a lack of straightforwardness is as possible, and as prejudicial, as in the spoken language of the tongue. If you wish to become acquainted with the truth of Nature, you must from the first resolve to deal with her sincerely.

Now remove your needle from its loop, and draw it from end to end along one of the ends of the magnet; resuspend it, and repeat your former experiment. You find the result different. You now find that each extremity of the magnet attracts one end of the needle, and repels the other. The simple attraction, observed in the first instance, is now replaced by a *dual* force. Repeat the experiment till you have thoroughly observed the ends which attract and those which repel each other.

Withdraw the magnet entirely from the vicinity of your needle, and leave the latter freely suspended by its fibre. Shelter it as well as you can from currents of air, and if you have iron buttons on your coat, or a steel penknife in your pocket, beware of their action. If you work at night, beware of iron candlesticks, or of brass ones with iron rods inside. Freed from such disturbances, the needle takes up a certain determinate position. It sets its length nearly north and south. Draw it aside from this position and let it go. After several oscillations it will again come to it. If you have obtained your magnet from a philosophical instrument maker, you will see a mark on one of its ends. Supposing, then, that you drew your needle along the end thus marked, and that the eye-end of your needle was the last to quit the magnet, you will find that the eye turns to the south, the point of the needle turning towards the north. Make sure of this, and do not take the statement on my authority.

Now take a second darning-needle like the first, and magnetise it in precisely the same manner: freely suspended it also will turn its point to the north and its eye to the south. Your next step is to examine the action of the two needles which you have thus magnetised upon each other.

Take one of them in your hand, and leave the other suspended; bring the eye-end of the former near the eye-end of the latter; the suspended needle retreats: it is repelled. Make the same experiment with the two points; you obtain the same result, the suspended needle is repelled. Now cause the dissimilar ends to act on each other—you have attraction—point attracts eye, and eye attracts point. Prove the reciprocity of this action by removing the suspended needle, and putting the other in its place. You obtain the same result. The attraction, then, is mutual, and the repulsion is mutual. You have thus demonstrated in the clearest manner the fundamental law of magnetism, that like poles repel, and that unlike poles attract, each other. You may say that this is all easily understood without doing; but *do it*, and your knowledge will not be confined to what I have uttered here.

I have said that one end of your magnet has a mark upon it; lay several silk fibres together, so as to get sufficient strength, or employ a thin silk ribbon, and form a loop large enough to hold your magnet. Suspend it; it turns its marked end towards the north. This marked end is that which in England is called the north pole. If a common smith has made your magnet, it will be convenient to determine its north pole yourself, and to mark it with a file. You vary your experiments by causing your magnetised darning-needle to attract and repel your large magnet; it is quite competent to do so. In magnetising the needle, I have supposed the eye-end to be the last to quit the marked end of the magnet; that end of the needle is a south pole. The end which last quits the magnet is always opposed in polarity to the end of the magnet with which it has been in contact. Brought near each other they mutually attract, and thus demonstrate that they are unlike poles.

You may perhaps learn all this in a single hour; but spend several at it, if necessary; and remember, understanding it is not sufficient: you must obtain a manual aptitude in addressing Nature. If you speak to your fellow-man you are not entitled to use jargon. Bad experiments are jargon addressed to Nature, and just as much to be deprecated. A manual dexterity in illustrating the interaction of magnetic poles is of the utmost importance at this stage of your progress; and you must not neglect attaining this power over your implements. As you proceed, moreover, you will be tempted to do more than I can possibly suggest. Thoughts will occur to you which you will endeavour to follow out; questions will arise which you will try to answer. The same experiment may be twenty things to twenty people. Having witnessed the action of pole on pole, through the air, you will perhaps try whether the magnetic power is not to be screened off. You use plates of glass, wood, slate, pasteboard, or gutta-percha, but find them all pervious to this wondrous force. One magnetic pole acts upon another through these bodies as if they were not present. And should you become a patentee for the regulation of ships' compasses, you will not fall, as some projectors have done, into the error of screening off the magnetism of the ship by the interposition of such substances.

If you wish to teach a class you must contrive that the effects which you have thus far witnessed for yourself shall be witnessed by twenty or thirty pupils. And here your private ingenuity must come into play. You will attach bits of paper to your needles, so as to render their movements visible at a distance, denoting the north and south poles by different colours, say green and red. You may also improve upon your darning-needle. Take a strip of sheet steel—the rib of a lady's stays will answer—heat it to vivid redness and plunge it into cold water. It is thereby hardened; rendered, in fact, almost as brittle as glass. Six inches of this, magnetised in the manner of the darning-needle, will be better able to carry your paper indexes. Having secured such a strip, you proceed thus:—

Magnetise a small sewing-needle and determine its poles; or, break half an inch, or an inch, off your magnetised darning-needle and suspend it by a fine silk fibre. The sewing-needle, or the fragment of the darning-needle, is now to be used as a test-needle, to examine the distribution of the magnetism in your strip of steel. Hold the strip upright in your left hand, and cause the test-needle to approach the lower end of your strip; one end is attracted, the other is repelled. Raise your needle along the strip; its oscillations, which at first were quick, become slower; opposite the middle of the strip they cease entirely; neither end of the needle is attracted; above the middle the test-needle turns suddenly round, its other end being now attracted. Go through the experiment thoroughly; you thus learn that the entire lower half of the strip attracts one end of the needle, while the entire upper half attracts the opposite end. Supposing the north end of your little needle to be that attracted below, you infer that the entire lower half of your magnetised strip exhibits south magnetism, while the entire upper half exhibits north magnetism. So far, then, you have determined the distribution of magnetism in your strip of steel.

You look at this fact, you think of it; in its suggestiveness the value of an experiment chiefly consists. The thought arises: 'What will occur if I break my strip of steel across in the middle? Shall I obtain two magnets each possessing a single pole?' Try the experiment; break your strip of steel, and test each half as you tested the whole. The mere presentation of its two ends in succession to your test-needle, suffices to show that you have *not* a magnet with a single pole—that each half possesses two poles with a neutral point between them. And if you again break the half into two other halves, you will find that each quarter of the original strip exhibist precisely the same magnetic distribution as the strip itself. You may continue the breaking process: no matter how small your fragment may be, it still possesses two opposite poles and a neutral point between them. Well, your hand ceases to break where breaking becomes a mechanical impossibility; but does the mind stop there? No: you follow the breaking process in idea when you can no longer realise it in fact; your thoughts wander amid the very atoms of your steel, and you conclude that each atom is a magnet, and that the force exerted by the strip of steel is the mere summation, or resultant, of the forces of its ultimate particles.

Here, then, is an exhibition of power which we can call forth at pleasure or cause to disappear. We magnetise our strip of steel by drawing it along the pole of a magnet; we can demagnetise it, or reverse its magnetism, by properly drawing it along the same pole in the opposite direction. What, then, is the real nature of this wondrous change? What is it that takes place among the atoms of the steel when the substance is magnetised? The question leads us beyond the region of sense, and into that of imagination. This faculty, indeed, is the divining-rod of the man of science. Not, however, an imagination which catches its creations from the air, but one informed and inspired by facts; capable of seizing firmly on a physical image as a principle, of discerning its consequences, and of devising means whereby these forecasts of thought may be brought to an experimental test. If such a principle be adequate to account for all the phenomena—if from an assumed cause the observed acts necessarily follow, we call the assumption a theory, and, once possessing it, we can not only revive at pleasure facts already known, but we can predict others which we have never seen. Thus, then, in the prosecution of physical science, our powers of observation, memory, imagination, and inference, are all drawn upon. We observe facts and store them up; imagination broods upon these memories, and by the aid of reason tries to discern their interdependence. The theoretic principle flashes or slowly dawns upon the mind; and then the deductive faculty interposes to carry out the principle to its logical consequences. A perfect theory gives dominion over natural facts; and even an assumption which can only partially stand the test of a comparison with facts, may be of eminent use in enabling us to connect and classify groups of phenomena. The theory of magnetic fluids is of this latter character, and with it we must now make ourselves familiar.

With the view of stamping the thing more firmly on your minds, I will make use of a strong and vivid image. In optics, red and green are called complementary colours; their mixture produces *white.* Now I ask you to imagine each of these colours to possess a self-repulsive power; that red repels red, and that green repels green; but that red attracts green and green attracts red, the attraction of the dissimilar colours being equal to the repulsion of the similar ones. Imagine the two colours mixed so as to produce white, and suppose two strips of wood painted with this white; what will be their action upon each other? Suspend one of them freely as we suspended our darning-needle, and bring the other near it; what will occur? The red component of the strip you hold in your hand will repel the red component of your suspended strip; but then it will attract the green, and, the forces being equal, they neutralise each other. In fact, the least reflection shows you that the strips will be as indifferent to each other as two unmagnetised darning-needles would be under the same circumstances.

But suppose, instead of mixing the colours, we painted one half of each strip from centre to end red, and the other half green, it is perfectly manifest that the two strips would now behave towards each other exactly as our two magnetised darning-needles—the red end would repel the red and attract the green, the green would repel the green and attract the red; so that, assuming two colours thus related to each other, we could by their mixture produce the neutrality of an unmagnetised body, while by their separation we could produce the duality of action of magnetised bodies.

But you have already anticipated a defect in my conception; for if we break one of our strips of wood in the middle we have one half entirely red, and the other entirely green, and with these it would be impossible to imitate the action of our broken magnet. How, then, must we modify our conception? We must evidently suppose *each molecule of wood* painted green on one face and red on the opposite one. The resultant action of all the atoms would then exactly resemble the action of a magnet. Here also, if the two opposite colours of each atom could be caused to mix so as to produce white, we should have, as before, perfect neutrality.

For these two self-repellent and mutually attractive colours, substitute in your minds two invisible self-repellent and mutually attractive fluids, which in ordinary steel are mixed to form a neutral compound, but which the act of magnetisation separates from each other, placing the opposite fluids on the opposite faces of each molecule. You have then a perfectly distinct conception of the celebrated theory of magnetic fluids. The strength of the magnetism excited is supposed to be proportional to the quantity of neutral fluid decomposed. According to this theory nothing is actually transferred from the exciting magnet to the excited steel. The act of magnetisation consists in the forcible separation of two fluids which existed in the steel before it was magnetised, but which then neutralised each other by their coalescence. And if you test your magnet, after it has excited a hundred pieces of steel, you will find that it has lost no force—no more, indeed, than I should lose, had my words such a magnetic influence on your minds as to excite in them a strong resolve to study natural philosophy. I should rather be the gainer by my own utterance, and by the reaction of your strength. The magnet also is the gainer by the reaction of the body which it magnetises.

Look now to your excited piece of steel; figure each molecule with its opposed fluids spread over its opposite faces. How can this state of things be permanent? The fluids, by hypothesis, attract each other; what, then, keeps them apart? Why do they not instantly rush together across the equator of the atom, and thus neutralise each other? To meet this question philosophers have been obliged to infer the existence of a special force, which holds the fluids asunder. They call it *coercive force*; and it is found that those kinds of steel which offer most resistance to being magnetised—which require the greatest amount of 'coercion' to tear their fluids asunder—are the very ones which offer the greatest resistance to the reunion of the fluids, after they have been once separated. Such kinds of steel are most suited to the formation of *permanent* magnets. It is manifest, indeed, that without coercive force a permanent magnet would not be at all possible.

You have not forgotten, that previous to magnetising your darning-needle *both* its ends were attracted by your magnet; and that both ends of your bit of iron wire were acted upon in the same way. Probably also long before this you will have dipped the end of your magnet among iron filings, and observed how they cling to it; or into a nail-box, and found how it drags the nails after it. I know very well that if you are not the slaves of routine, you will have by this time done many things that I have not told you to do, and thus multiplied your experience beyond what I have indicated. You are almost sure to have caused a bit of iron to hang from the end of your magnet, and you have probably succeeded in causing a second piece to attach itself to the first, a third to the second; until finally the force has become too feeble to bear the weight of more. If you have operated with nails, you may have observed that the points and edges hold together with the greatest tenacity; and that a bit of iron clings more firmly to the corner of your magnet than to one of its flat surfaces. In short, you will in all likelihood have enriched your experience in many ways without any special direction from me.

Well, the magnet attracts the nail, and that nail attracts a second one. This proves that the nail in contact with the magnet has had the magnetic quality developed in it by that contact. If it be withdrawn from the magnet its power to attract its fellow nail ceases. Contact, however, is not necessary. A sheet of glass or paper, or a space of air, may exist between the magnet and the nail; the latter is still magnetised, though not so forcibly as when in actual contact. The nail thus presented to the magnet is itself a temporary magnet. That end which is turned towards the magnetic pole has the opposite magnetism of the pole which excites it; the end most remote from the pole has the same magnetism as the pole itself, and between the two poles the nail, like the magnet, possesses a magnetic equator.

Conversant as you now are with the theory of magnetic fluids, you have already, I doubt not, anticipated me in imagining the exact condition of iron under the influence of the magnet. You picture the iron as possessing the neutral fluid in abundance; you picture the magnetic pole, when brought near, decomposing the fluid; repelling the fluid of a like kind with itself, and attracting the unlike fluid; thus exciting in the parts of the iron nearest to itself the opposite polarity. But the iron is incapable of becoming a permanent magnet. It only shows its virtue as long as the magnet acts upon it. What, then, does the iron lack which the steel possesses? It lacks coercive force. Its fluids are separated with ease; but, once the separating cause is removed, they flow together again, and neutrality is restored. Your imagination must be quite nimble in picturing these changes. You must be able to see the fluids dividing and reuniting, according as the magnet is brought near or withdrawn. Fixing a definite pole in your imagination, you must picture the precise arrangement of the two fluids with reference to this pole. And you must not only be well drilled in the use of this mental imagery yourself, but you must be able to arouse the same pictures in the minds of your pupils. You ought to satisfy yourself that they possess the power of placing magnets and iron in various positions, and describing the exact magnetic state of the iron in each particular case. The mere facts of magnetism will have their interest immensely augmented by an acquaintance with those hidden principles whereon the facts depend. Still, while you use this theory of magnetic fluids, to track out the phenomena and link them together, be sure to tell your pupils that it is to be regarded as a symbol merely,—a symbol, moreover, which is incompetent to cover all the facts,[1] but which does good practical service whilst we are waiting for the actual truth.

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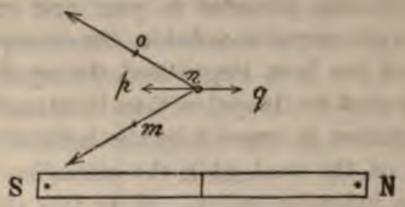
[1] This theory breaks down when applied to diamagnetic bodies, which are repelled by magnets. Like soft iron, such bodies are thrown into a state of temporary excitement, in virtue of which they are repelled; but any attempt to explain such a repulsion by the decomposition of a fluid will demonstrate its own futility.

This state of excitement into which the annealed iron is thrown by the influence of the magnet, is sometimes called 'magnetisation by influence.' More commonly, however, the magnetism is said to be 'induced' in the iron, and hence this mode of magnetising is called 'magnetic induction.' Now, there is nothing theoretically perfect in Nature: there is no iron so soft as not to possess a certain amount of coercive force, and no steel so hard as not to be capable, in some degree, of magnetic induction. The quality of steel is in some measure possessed by iron, and the quality of iron is shared in some degree by steel. It is in virtue of this latter fact that the unmagnetised darning-needle was attracted in your first experiment; and from this you may at once deduce the consequence that, after the steel has been magnetised, the repulsive action of a magnet must be always less than its attractive action. For the repulsion is opposed by the inductive action of the magnet on the steel, while the attraction is assisted by the same inductive action. Make this clear to your minds, and verify it by your experiments. In some cases you can actually make the attraction due to the temporary magnetism overbalance the repulsion due to the permanent magnetism, and thus cause two poles of the same kind apparently to attract each other. When, however, good hard magnets act on each other from a sufficient distance, the inductive action practically vanishes, and the repulsion of like poles is sensibly equal to the attraction of unlike ones.

I dwell thus long on elementary principles, because they are of the first importance, and it is the temptation of this age of unhealthy cramming to neglect them. Now follow me a little farther. In examining the distribution of magnetism in your strip of steel you raised the needle slowly from bottom to top, and found what we called a neutral point at the centre. Now does the magnet really exert no influence on the pole presented to its centre? Let us see.

Let S N, fig. 7, be our magnet, and let *n* represent a particle of north magnetism placed exactly opposite the middle of the magnet. Of course this is an imaginary case, as you can never in reality thus detach your north magnetism from its neighbour. What is the action of the two poles of the magnet on *n*? Your reply will of course be that the pole S attracts *n* while the pole N repels it. Let the magnitude and direction of the attraction be expressed by the line *n m*, and the magnitude and direction of the repulsion by the line *n o*. Now, the particle *n* being equally distant from S and N, the line *n o*, expressing the repulsion, will be equal to *m n*, which expresses the attraction. Acted upon by two such forces, the particle *n* must evidently move in the direction *p n*, exactly midway between *m n* and *n o*. Hence you see that, although there is no tendency of the particle *n* to move towards the magnetic equator, there is a tendency on its part to move parallel to the magnet. If, instead of a particle of north magnetism, we placed a particle of south magnetism opposite to the magnetic equator, it would evidently be urged along the line *n q*; and if, instead of two separate particles of magnetism, we place a little magnetic needle, containing both north and south magnetism, opposite the magnetic equator, its south pole being urged along *n q*, and its north along *n p*, the little

FIG. 7.

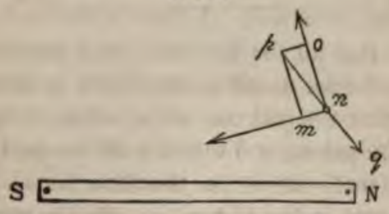


needle will be compelled to set itself parallel to the magnet S N. Make the experiment, and satisfy yourselves that this is a true deduction.

Substitute for your magnetic needle a bit of iron wire, devoid of permanent magnetism, and it will set itself exactly as the needle does. Acted upon by the magnet, the wire, as you know, becomes a magnet and behaves as such; it will, of course, turn its north pole towards *p*, and south pole towards *q*, just like the needle.

But supposing you shift the position of your particle of north magnetism, and bring it nearer to one end of your magnet than to the other; the forces acting on the particle are no longer equal; the nearest pole of the magnet will act more powerfully on the particle than the more distant one. Let S N, fig. 8, be the magnet, and *n* the particle of north magnetism, in its new position. Well, it is repelled by N, and attracted by S. Let the repulsion be represented in magnitude and direction by the line *n o*, and the attraction by the shorter line *n m*. The resultant of these two forces will be found by completing the parallelogram *m n o p*, and drawing its diagonal *n p*. Along *n p*, then, a particle of north magnetism would be urged by the simultaneous action of S and N. Substituting a particle of south magnetism for *n*, the same reasoning would lead to the conclusion that the particle would be urged along *n q*. If we place at *n* a short magnetic needle, its north pole will be urged along *n p*, its south

FIG. 8.

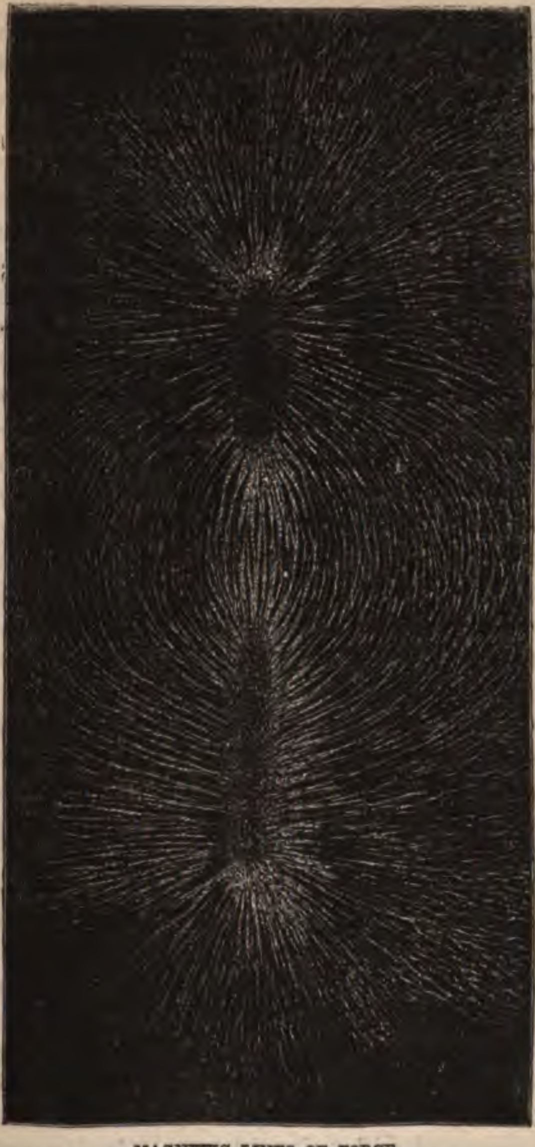


pole along *n q*, the only position possible to the needle, thus acted on, being along the line *p q*, which is no longer parallel to the magnet. Verify this deduction by actual experiment.

In this way we might go round the entire magnet; and, considering its two poles as two centres from which the force emanates, we could, in accordance with ordinary mechanical principles, assign a definite direction to the magnetic needle at every particular place. And substituting, as before, a bit of iron wire for the magnetic needle, the positions of both will be the same.

Now, I think, without further preface, you will be able to comprehend for yourselves, and explain to others, one of the most interesting effects in the whole domain of magnetism. Iron filings you know are particles of iron, irregular in shape, being longer in some directions than in others. For the present experiment, moreover, instead of the iron filings, very small scraps of thin iron wire might be employed. I place a sheet of paper over the magnet; it is all the better if the paper be stretched on a wooden frame, as this enables us to keep it quite level. I scatter the filings, or the scraps of wire, from a sieve upon the paper, and tap the latter gently, so as to liberate the particles for a moment from its friction. The magnet acts on the filings through the paper, and see how it arranges them! They embrace the magnet in a series of beautiful curves, which are technically called 'magnetic curves,' or 'lines of magnetic force.' Does the meaning of these lines yet flash upon you? Set your magnetic needle, or your suspended bit of wire, at any point of one of the curves, and you will find the direction of the needle, or of the wire, to be exactly that of the particle of iron, or of the magnetic curve, at the point. Go round and round the magnet; the direction of your needle always coincides with the direction of the curve

Fig. 9.



MAGNETIC LINES OF FORCE.

From a Photograph by Professor Mayer.

on which it is placed. These, then, are the lines along which a particle of south magnetism, if you could detach it, would move to the north pole, and a bit of north magnetism to the south pole. They are the lines along which the decomposition of the neutral fluid takes place. In the case of the magnetic needle, one of its poles being urged in one direction, and the other pole in the opposite direction, the needle must necessarily set itself as a *tangent* to the curve. I will not seek to simplify this subject further. If there be anything obscure or confused or incomplete in my statement, you ought now, by patient thought, to be able to clear away the obscurity, to reduce the confusion to order, and to supply what is needed to render the explanation complete. Do not quit the subject until you thoroughly understand it; and if you are then able to look with your mind's eye at the play of forces around a magnet, and see distinctly the operation of those forces in the production of the magnetic curves, the time which we have spent together will not have been spent in vain.

In this thorough manner we must master our materials, reason upon them, and, by determined study, attain to clearness of conception. Facts thus dealt with exercise an expansive force upon the boundaries of thought;—they widen the mind to generalisation. We soon recognise a brotherhood between the larger phenomena of Nature and the minute effects which we have observed in our private chambers. Why, we enquire, does the magnetic needle set north and south? Evidently it is compelled to do so by the earth; the great globe which we inherit is itself a magnet. Let us learn a little more about it. By means of a bit of wax, or otherwise, attach the middle point of your silk fibre to your magnetic needle; the needle will thus be uninterfered with by the paper loop, and will enjoy to some extent a power of 'dipping' its point, or its eye, below the horizon. Lay your magnet on a table, and hold the needle over the equator of the magnet. The needle sets horizontal. Move it towards the north end of the magnet; the south end of the needle dips, the dip augmenting as you approach the north pole, over which the needle, if free to move, will set itself exactly vertical. Move it back to the centre, it resumes its horizontality; pass it on towards the south pole, its north end now dips, and directly over the south pole the needle becomes vertical, its north end being now turned downwards. Thus we learn that on the one side of the magnetic equator the north end of the needle dips: on the other side the south end dips, the dip varying from nothing to 90°. If we go to the equatorial regions of the earth with a suitably suspended needle we shall find there the position of the needle horizontal. If we sail north one end of the needle dips; if we sail south the opposite end dips; and over the north or south terrestrial magnetic pole the needle sets vertical. The south magnetic pole has not yet been found, but Sir James Ross discovered the north magnetic pole on June 1, 1831. In this manner we establish a complete parallelism between the action of the earth and that of an ordinary magnet.

The terrestrial magnetic poles do not coincide with the geographical ones; nor does the earth's magnetic equator quite coincide with the geographical equator. The direction of the magnetic needle in London, which is called the magnetic meridian, encloses an angle of 24° with the true astronomical meridian, this angle being called the Declination of the needle for London. The north pole of the needle now lies to the west of the true meridian; the declination is westerly. In the year 1660, however, the declination was nothing, while before that time it was easterly. All this proves that the earth's magnetic constituents are gradually changing their distribution. This change is very slow; it is technically called the *secular change*, and the observation of it has not yet extended over a sufficient period to enable us to guess, even approximately, at its laws.

Having thus discovered, to some extent, the secret of the earth's power, we can turn it to account. I hold in my hand a poker formed of good soft iron; it is now in the line of dip—a tangent, in fact, to the earth's line of magnetic force. The earth, acting as a magnet, is at this moment constraining the two fluids of the poker to separate, making the lower end of the poker a north pole, and the upper end a south pole. Mark the experiment: I hold the knob uppermost, and it attracts the north end of a magnetic needle. I now reverse the poker, bringing its knob undermost; the knob is now a north pole and attracts the south end of a magnetic needle. Get such a poker and carefully repeat this experiment; satisfy yourselves that the fluids shift their position, according to the manner in which the poker is presented to the earth. It has already been stated that the softest iron possesses a certain amount of coercive force. The earth, at this moment, finds in this force an antagonist which opposes the full decomposition of the neutral fluid. The component fluids may be figured as meeting an amount of friction, or possessing an amount of adhesion, which prevents them from gliding over the molecules of the poker. Can we assist the earth in this case? If we wish to remove the residue of a powder from the interior surface of a glass to which the powder clings, we invert the glass, tap it, loosen the hold of the powder, and thus enable the force of gravity to pull it down. So also by tapping the end of the poker we loosen the adhesion of the fluids to the molecules and enable the earth to pull them apart. But, what is the consequence? The portion of fluid which has been thus forcibly dragged over the molecules refuses to return when the poker has been removed from the line of dip; the iron, as you see, has become a permanent magnet. By reversing its position and tapping it again we reverse its magnetism. A thoughtful and competent teacher will well know how to place these remarkable facts before his pupils in a manner which will excite their interest. By the use of sensible images, more or less gross, he will first give those whom he teaches definite conceptions, purifying these conceptions more and more, as the minds of his pupils become more capable of abstraction. He will cause his logic to run like a line of light through these images, and by thus acting he will cause his boys to march at his side with a profit and a joy which the mere exhibition of facts without principles, or the appeal to the bodily senses and the power of memory alone, could never inspire.

As an expansion of the note at p. 259, the following extract may find a place here:—

'It is well known that a voltaic current exerts an attractive force upon a second current, flowing in the same direction; and that when the directions are opposed to each other the force exerted is a repulsive one. By coiling wires into spirals, Ampère was enabled to make them produce all the phenomena of attraction and repulsion exhibited by magnets, and from this it was but a step to his celebrated theory of molecular currents. He supposed the molecules of a magnetic body to be surrounded by such currents, which, however, in the natural state of the body mutually neutralised each other, on account of their confused grouping. The act of magnetisation he supposed to consist in setting these molecular currents parallel to each other; and, starting from this principle, he reduced all the phenomena of magnetism to the mutual action of electric currents.

'If we reflect upon the experiments recorded in the foregoing pages from first to last, we can hardly fail to be convinced that diamagnetic bodies operated on by magnetic forces possess a polarity "the same in kind as, but the reverse in direction of, that acquired by magnetic bodies." But if this be the case, how are we to conceive the *physical mechanism* of this polarity?

According to Coulomb's and Poisson's theory, the act of magnetisation consists in the decomposition of a neutral magnetic fluid; the north pole of a magnet, for example, possesses an attraction for the south fluid of a piece of soft iron submitted to its influence, draws the said fluid towards it, and with it the material particles with which the fluid is associated. To account for diamagnetic phenomena this theory seems to fail altogether; according to it, indeed, the oft-used phrase, "a north pole exciting a north pole, and a south pole a south pole," involves a contradiction. For if the north fluid be supposed to be *attracted* towards the influencing north pole, it is absurd to suppose that its presence there could produce *repulsion*. The theory of Ampère is equally at a loss to explain diamagnetic action; for if we suppose the particles of bismuth surrounded by molecular currents, then, according to all that is known of electro-dynamic laws, these currents would set themselves parallel to, and in the same direction as, those of the magnet, and hence attraction, and not repulsion, would be the result. The fact, however, of this not being the case, proves that these molecular currents are not the mechanism by which diamagnetic induction is effected. The consciousness of this, I doubt not, drove M. Weber to the assumption that the phenomena of diamagnetism are produced by molecular currents, not *directed*, but actually *excited* in the bismuth by the magnet. Such induced currents would, according to known laws, have a direction *opposed* to those of the inducing magnet, and hence would produce the phenomena of repulsion. To carry out the assumption here made, M. Weber is obliged to suppose that the molecules of diamagnetic bodies are surrounded by channels, in which the induced molecular currents, once excited, continue to flow without resistance.'—*Diamagnetism and Magne-crystallic Action*, p. 136–7.

XII.

DEATH BY LIGHTNING.

PEOPLE in general imagine, when they think at all about the matter, that an impression upon the nerves—a blow, for example, or the prick of a pin—is felt at the moment it is inflicted. But this is not the case. The seat of sensation is the brain, and to it the intelligence of any impression made upon the nerves has to be transmitted before this impression can become manifest in consciousness. The transmission, moreover, requires *time*, and the consequence is, that a wound inflicted on a portion of the body distant from the brain is more tardily appreciated than one inflicted adjacent to the brain. By an extremely ingenious experimental arrangement, Helmholtz has determined the velocity of this nervous transmission, and finds it to be about one hundred feet a second, or less than one-tenth of the velocity of sound in air. If, therefore, a whale fifty feet long were wounded in the tail, it would not be conscious of the injury till half a second after the wound had been inflicted.[1] But this is not the only ingredient in the delay. There can scarcely be a doubt that to every act of consciousness belongs a determinate molecular arrangement of the brain—that every thought or feeling has its physical correlative in that organ; and nothing can be more certain than that every physical change, whether molecular or mechanical, requires time for its accomplishment. So that, besides the interval of transmission, a still further time is necessary for the brain to put itself in order—for its molecules to take up the motions or positions necessary to the completion of consciousness. Helmholtz considers that one-tenth of a second is demanded for this purpose. Thus, in the case of the whale above supposed, we have first half a second consumed in the transmission of the intelligence through the sensor nerves to the head, one-tenth of a second consumed by the brain in completing the arrangements necessary to consciousness, and, if the velocity of transmission through the motor be the same as that through the sensor nerves, half a second in sending a command to the tail to defend itself. Thus one second and a tenth would elapse before an impression made upon its caudal nerves could be responded to by a whale fifty feet long.

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[1] A most admirable lecture on the velocity of nervous transmission has been published by Dr. Du Bois Reymond in the 'Proceedings of the Royal Institution' for 1866, vol. iv. p. 575.

Now, it is quite conceivable that an injury might be inflicted which would render the nerves unfit to be the conductors of the motion which results in sensation; and if such a thing occurred, no matter how severe the injury might be, we should not be conscious of it. Or it may be, that long before the time required by the brain to complete the arrangements necessary to consciousness, its power of arrangement might be wholly suspended. In such a case also, though the injury might be of a nature to cause death, this would occur without feeling of any kind. Death in this case would be simply the sudden negation of life, without any intervention of consciousness whatever.

Doubtless there are many kinds of death of this character. The passage of a musket-bullet through the brain is a case in point; and the placid aspect of a man thus killed is in perfect accordance with the conclusion which might be drawn *à priori* from the experiments of Helmholtz. Cases of insensibility, moreover, are not uncommon which do not result in death, and after which the persons affected have been able to testify that no pain was felt prior to the loss of consciousness.

The time required for a rifle-bullet to pass clean through a man's head may be roughly estimated at a thousandth of a second. Here, therefore, we should have no room for sensation, and death would be painless. But there are other actions which far transcend in rapidity that of the rifle-bullet. A flash of lightning cleaves a cloud, appearing and disappearing in less than a hundred-thousandth of a second, and the velocity of electricity is such as would carry it in a single second over a distance almost equal to that which separates the earth and moon. It is well known that a luminous impression once made upon the retina endures for about one-sixth of a second, and that this is the reason why we see a ribbon of light when a glowing coal is caused to pass rapidly through the air. A body illuminated by an instantaneous flash continues to be seen for the sixth of a second after the flash has become extinct; and if the body thus illuminated be in motion, it appears at rest at the place where the flash falls upon it. The colour-top is familiar to most of us. By this instrument a disk with differently-coloured sectors is caused to rotate rapidly; the colours blend together, and, if they are chosen in the proper proportions, when the motion is sufficiently rapid the disk appears white. Such a top, rotating in a dark room and illuminated by an electric spark, appears motionless, each distinct colour being clearly seen. Professor Dove has found that a flash of lightning produces the same effect. During a thunder-storm he put a colour-top in exceedingly rapid motion, and found that every flash revealed the top as a motionless object with its colours distinct. If illuminated solely by a flash of lightning, the motion of all bodies on the earth's surface would, as Dove has remarked, appear suspended. A cannon-ball, for example, would have its flight apparently arrested, and would seem to hang motionless in space as long as the luminous impression which revealed the ball remained upon the eye.

If, then, a rifle-bullet move with sufficient rapidity to destroy life without the interposition of sensation, much more is a flash of lightning competent to produce this effect. Accordingly, we have well-authenticated cases of people being struck senseless by lightning who, on recovery, had no memory of pain. The following circumstantial case is described by Hemmer:—

On June 30, 1788, a soldier in the neighbourhood of Mannheim, being overtaken by rain, placed himself under a tree, beneath which a woman had previously taken shelter. He looked upwards to see whether the branches were thick enough to afford the required protection, and, in doing so, was struck by lightning, and fell senseless to the earth. The woman at his side experienced the shock in her foot, but was not struck down. Some hours afterwards the man revived, but remembered nothing about what had occurred, save the fact of his looking up at the branches. This was his last act of consciousness, and he passed from the conscious to the unconscious condition without pain. The visible marks of a lightning stroke are usually insignificant: the hair is sometimes burnt; slight wounds are observed; while, in some instances, a red streak marks the track of the discharge over the skin.

Under ordinary circumstances, the discharge from a small Leyden jar is exceedingly unpleasant to me. Some time ago I happened to stand in the presence of a numerous audience, with a battery of fifteen large Leyden jars charged beside me. Through some awkwardness on my part, I touched a wire leading from the battery, and the discharge went through my body. Life was absolutely blotted out for a very sensible interval, without a trace of pain. In a second or so consciousness returned; I saw myself in the presence of the audience and apparatus, and, by the help of these external appearances, immediately concluded that I had received the battery discharge. The *intellectual* consciousness of my position was restored with exceeding rapidity, but not so the *optical* consciousness. To prevent the audience from being alarmed, I observed that it had often been my desire to receive accidentally such a shock, and that my wish had at length been fulfilled. But, while making this remark, the appearance which my body presented to myself was that of a number of separate pieces. The arms, for example, were detached from the trunk, and seemed suspended in the air. In fact, memory and the power of reasoning appeared to be complete long before the optic nerve was restored to healthy action. But what I wish chiefly to dwell upon here is, the absolute painlessness of the shock; and there cannot be a doubt that, to a person struck dead by lightning, the passage from life to death occurs without consciousness being in the least degree implicated. It is an abrupt stoppage of sensation, unaccompanied by a pang.

July 8, 1865.

XIII.

SCIENCE AND THE 'SPIRITS.'

THEIR refusal to investigate 'spiritual phenomena' is often urged as a reproach to scientific men. I here propose to give a sketch of an attempt to apply to the 'phenomena' those methods of enquiry which are found available in dealing with natural truth.

Some time ago, when the spirits were particularly active in this country, a celebrated philosopher was invited, or rather entreated, by one of his friends to meet and question them. He had, however, already made their acquaintance, and did not wish to renew it. I had not been so privileged, and he therefore kindly arranged a transfer of the invitation to me. The spirits themselves named the time of meeting, and I was conducted to the place at the day and hour appointed.

Absolute unbelief in the facts was by no means my condition of mind. On the contrary, I thought it probable that some physical principle, not evident to the spiritualists themselves, might underlie their manifestations. Extraordinary effects are produced by the accumulation of small impulses. Galileo set a heavy pendulum in motion by the well-timed puffs of his breath. Ellicot set one clock going by the ticks of another, even when the two clocks were separated by a wall. Preconceived notions can, moreover, vitiate, to an extraordinary degree, the testimony of even veracious persons. Hence my desire to witness those extraordinary phenomena, the existence of which seemed placed beyond a doubt by the known veracity of those who had witnessed and described them. The meeting took place at a private residence in the neighbourhood of London. My host, his intelligent wife, and a gentleman who may be called X., were in the house when I arrived. I was informed that the 'medium' had not yet made her appearance; that she was sensitive, and might resent suspicion. It was therefore requested that the tables and chairs should be examined before her arrival, in order to be assured that there was no trickery in the furniture. This was done; and I then first learned that my hospitable host had arranged that the *séance* should be a dinner-party. This was to me an unusual form of investigation; but I accepted it, as one of the accidents of the occasion.

The 'medium' arrived—a delicate-looking young lady, who appeared to have suffered much from ill-health. I took her to dinner and sat close beside her. Facts were absent for a considerable time, a series of very wonderful narratives supplying their place. The duty of belief on testimony was frequently insisted on. X. appeared to be a chosen spiritual agent, and told us many surprising things. He affirmed that, when he took a pen in his hand, an influence ran from his shoulder downwards, and impelled him to write oracular sentences. I listened for a time, offering no observation. 'And now,' continued X., 'this power has so risen as to reveal to me the thoughts of others. Only this morning I told a friend what he was thinking of, and what he intended to do during the day.' Here, I thought, is something that can be at once tested. I said immediately to X.: 'If you wish to win to your cause an apostle, who will proclaim your principles to the world without fear, tell me what I am now thinking of.' X. reddened, and did *not* tell me my thought.

Some time previously I had visited Baron Reichenbach, in Vienna, and I now asked the young lady who sat beside me, whether she could see any of the curious things which he describes—the light emitted by crystals, for example? Here is the conversation which followed, as extracted from my notes, written on the day following the *séance.*

Medium.—'Oh, yes; but I see light around all bodies.'

I.—'Even in perfect darkness?'

Medium.—'Yes; I see luminous atmospheres round all people. The atmosphere which surrounds Mr. R. C. would fill this room with light.'

I.—'You are aware of the effects ascribed by Baron Reichenbach to magnets?'

Medium.—'Yes; but a magnet makes me terribly ill.'

I.—'Am I to understand that, if this room were perfectly dark, you could tell whether it contained a magnet, without being informed of the fact?'

Medium.—'I should know of its presence on entering the room.'

I.—'How?'

Medium.—'I should be rendered instantly ill.'

I.—'How do you feel to-day?'

Medium.—'Particularly well; I have not been so well for months.'

I.—'Then, may I ask you whether there is, at the present moment, a magnet in my possession?'

The young lady looked at me, blushed, and stammered,

'No; I am not *en rapport* with you.'

I sat at her right hand, and a left-hand pocket, within six inches of her person, contained a magnet.

Our host here deprecated discussion, as it 'exhausted the medium.' The wonderful narratives were resumed; but I had narratives of my own quite as wonderful. These spirits, indeed, seemed clumsy creations, compared with those with which my own researches had made me familiar. I therefore began to match the wonders related to me by other wonders. A lady present discoursed on spiritual atmospheres, which she could see as beautiful colours when she closed her eyes. I professed myself able to see similar colours, and, more than that, to be able to see the interior of my own eyes. The medium affirmed that she could see actual waves of light coming from the sun. I retorted that men of science could tell the exact number of waves emitted in a second, and also their exact length. The medium spoke of the performances of the spirits on musical instruments. I said that such performance was gross, in comparison with a kind of music which had been discovered some time previously by a scientific man. Standing at a distance of twenty feet from a jet of gas, he could command the flame to emit a melodious note; it would obey, and continue its song for hours. So loud was the music emitted by the gas-flame, that it might be heard by an assembly of a thousand people. These were acknowledged to be as great marvels as any of those of spiritdom. The spirits were then consulted, and I was pronounced to be a first-class medium.

During this conversation a low knocking was heard from time to time under the table. These were the spirits' knocks. I was informed that one knock, in answer to a question, meant 'No;' that two knocks meant 'Not yet;' and that three knocks meant 'Yes.' In answer to the question whether I was a medium, the response was three brisk and vigorous knocks. I noticed that the knocks issued from a particular locality, and therefore requested the spirits to be good enough to answer from

scope. The spirits seemed disconcerte
lost their playfulness, and did not qu
considerable time.

Somewhat weary of the proceedi
myself back against my chair and gaz
the window. While thus engaged, th
pushed. Attention was drawn to the
ing in the glasses, and I was asked wh
convincing. I readily granted the fa
began to feel the delicacy of my posi
several pairs of arms upon the table, a
legs under it; but how was I, without
the conviction which I really entertain
the difficulty, I again turned a wine-
and rested my ear upon it. The rim
not level, and the hair, on touching
vibrate, and produce a peculiar buzzin
fectly candid and warm-hearted old
opposite side of the table, whom I
attention to the sound, and expressed
that it was spiritual. I, however, info
was the moving hair acting on the gla
tion was not well received; and X., i
pleasantry, demanded whether it was

the evening this pulling of the table occurred, or rather was attempted, three times. Twice the table moved when my attention was withdrawn from it; on a third occasion, I tried whether the act could be provoked by an assumed air of inattention. Grasping the table firmly between my knees, I threw myself back in the chair, and waited, with eyes fixed on vacancy, for the pull. It came. For some seconds it was pull spirit, hold muscle; the muscle, however, prevailed, and the table remained at rest. Up to the present moment, this interesting fact is known only to the particular spirit in question and myself.

A species of mental scene-painting, with which my own pursuits had long rendered me familiar, was employed to figure the changes and distribution of spiritual power. The spirits were provided with atmospheres, which combined with and interpenetrated each other, considerable ingenuity being shown in demonstrating the necessity of *time* in effecting the adjustment of the atmospheres. In fact, just as in science, the senses, time, and space constituted the conditions of the phenomena. A rearrangement of our positions was proposed and carried out; and soon afterwards my attention was drawn to a scarcely sensible vibration on the part of the table. Several persons were leaning on the table at the time, and I asked permission to touch the medium's hand. 'Oh! I know I tremble,' was her reply. Throwing one leg across the other, I accidentally nipped a muscle, and produced thereby an involuntary vibration of the free leg. This vibration, I knew, must be communicated to the floor, and thence to the chairs of all present. I therefore intentionally promoted it. My attention was promptly drawn to the motion; and a gentleman beside me, whose value as a witness I was particularly desirous to test, expressed his belief that it was out of the compass of human power to produce so strange a tremor. 'I believe,' he added, earnestly, 'that it is entirely the spirits' work.' 'So do I,' added, with heat, the candid and warmhearted old gentleman A. 'Why, sir,' he continued, 'I feel them at this moment shaking my chair.' I stopped the motion of the leg. 'Now, sir,' A. exclaimed, 'they are gone.' I began again, and A. once more ejaculated. I could, however, notice that there were doubters present, who did not quite know what to think of the manifestations. I saw their perplexity; and, as there was sufficient reason to believe that the disclosure of the secret would simply provoke anger, I kept it to myself.

Again a period of conversation intervened, during which the spirits became animated. The evening was confessedly a dull one, but matters appeared to brighten towards its close. The spirits were requested to spell the name by which I am known in the heavenly world. Our host commenced repeating the alphabet, and when he reached the letter 'P' a knock was heard. He began again, and the spirits knocked at the letter 'O.' I was puzzled, but waited for the end. The next letter knocked down was 'E.' I laughed, and remarked that the spirits were going to make a poet of me. Admonished for my levity, I was informed that the frame of mind proper for the occasion ought to have been superinduced by a perusal of the Bible immediately before the *séance*. The spelling, however, went on, and sure enough I came out a poet. But matters did not end here. Our host continued his repetition of the alphabet, and the next letter of the name proved to be 'O.' Here was manifestly an unfinished word; and the spirits were apparently in their most communicative mood. The knocks came from under the table, but no person present evinced the slightest desire to look under it. I asked whether I might go underneath; the permission was granted; so I crept under the table. Some tittered; but the candid old A. exclaimed, 'He has a right to look into the very dregs of it, to convince himself.' Having pretty well assured myself that no sound could be produced under the table without its origin being revealed, I requested our host to continue his questions. He did so, but in vain. He adopted a tone of tender entreaty; but the 'dear spirits' had become dumb dogs, and refused to be entreated. I continued under that table for at least a quarter of an hour, after which, with a feeling of despair as regards the prospects of humanity never before experienced, I regained my chair. Once there, the spirits resumed their loquacity, and dubbed me 'Poet of Science.'

This, then, is the result of an attempt made by a scientific man to look into these spiritual phenomena. It is not encouraging; and for this reason: The present promoters of spiritual phenomena divide themselves into two classes, one of which needs no demonstration, while the other is beyond the reach of proof. The victims like to believe, and they do not like to be undeceived. Science is perfectly powerless in the presence of this frame of mind. It is, moreover, a state perfectly compatible with extreme intellectual subtlety and a capacity for devising hypotheses which only require the hardihood engendered by strong conviction, or by callous mendacity, to render them impregnable. The logical feebleness of science is not sufficiently borne in mind. It keeps down the weed of superstition, not by logic but by slowly rendering the mental soil unfit for its cultivation. When science appeals to uniform experience, the spiritualist will retort, 'How do you know that a uniform experience will continue uniform? You tell me that the sun has risen for six thousand years: that is no proof that it will rise to-morrow; within the next twelve hours it may be puffed out by the Almighty.' Taking this ground, a man may maintain the story of 'Jack and the Beanstalk' in the face of all the science in the world. You urge, in vain, that science has given us all the knowledge of the universe which we now possess, while spiritualism has added nothing to that knowledge. The drugged soul is beyond the reach of reason. It is in vain that impostors are exposed, and the special demon cast out. He has but slightly to change his shape, return to his house, and find it 'empty, swept, and garnished.'

December 10, 1864.

PART II.

INTRODUCTION.

IN consequence of their special character, the Fragments of Part II. have been separated from the more purely scientific ones of Part I., and placed together in the order of their publication. Thus presented, they will, I think, make it plain that, within the last two years, I have added no material iniquity to the list previously recorded against me. I have gone carefully over them all this year in Switzerland, bestowing special attention upon the one which has given most offence. To the judgment of thoughtful men I now commit them: the unthoughtful and the unfair will not read them, though they will continue to abuse them.

I have no desire to repay in kind the hard words already thrown at them and me; but a simple comparison will make clear to my more noisy and unreasonable assailants how I regard their position. To the nobler Bereans of the press and pulpit, who have honoured me with their attention, I do not now refer. Webster defines a squatter as one who settles on new land without a title. This, in regard to Anthropology and Cosmogony, I hold to have been the position of the older theologians; and what their heated successors of to-day denounce as 'a raid upon Theology,' is, in my opinion, a perfectly legal and equitable attempt to remove them from ground which they have no right to hold.

If the title exist, let it be produced. It is not the revision of the text of Genesis by accomplished scholars that the public so much need, as to be informed and convinced how far the text, polished or unpolished, has a claim upon the belief of intelligent persons. It is, I fear, a growing conviction that our ministers of religion, for the sake of peace, more or less sacrifice their sincerity in dealing with the Cosmogony of the Old Testament. I notice this in conversation, and it is getting into print. Before me, for example, is a little *brochure*, in which a layman presses a clerical friend with a series of questions regarding Creation—the six-day period of Divine activity, the destruction of the world by a flood, the building of an ark, the placing of creatures in it by pairs, and the descent from this ancestry of all living things, 'men and women, birds and beasts.' He asks his friend, 'Do you *without any mental reservation* believe these things?' 'If you *do*,' he continues, 'then I can only say that the accumulated and accepted knowledge of mankind, including the entire sciences of Astronomy, Geology, Philology, and History, are [as far as you are concerned] nought and mistaken. If you do *not* believe those events to have so happened, or do so with some mental reservation, which destroys the whole sense and meaning of the narrative, *why do you not say so from your pulpits?*'

The friend merely parries and evades the question. According to Mr. Martineau, the clergy speak very differently indeed from their pulpits. After showing how the Mosaic picture of the 'genetic order of things' has been not only altered but inverted by scientific research, he says: 'Notwithstanding the deplorable condition to which the picture has been reduced, it is exhibited fresh every week to millions taught to believe it as divine.' It cannot be urged that error here does no practical harm, or that it does not act to the detriment of honest men. It was for openly avowing doubts which, it is said, others discreetly entertain, that the Bishop of Natal suffered persecution; it was for his public fidelity to scientific truth, as far as his lights extended, that he was branded, even during his recent visit to this country, as an 'excommunicated heretic.' The courage of Dean Stanley and of the Master of Balliol, in reference to this question, disarmed indignation, and caused the public to overlook a wrong which might not otherwise have been endured.

The liberal and intelligent portion of Christendom must, I take it, differentiate itself more and more, in word and act, from the fanatical, foolish, and more purely sacerdotal portion. Enlightened Roman Catholics are more especially bound to take action here; for the travesty of heaven and earth is grosser, and the attempt to impose it on the world is more serious, in their community than elsewhere. That they are more or less alive to this state of things, and that they show an increasing courage and independence in their demands for education, will be plain to the reader of the 'Apology for the Belfast Address.' The 'Memorial' there referred to was the impatient protest of barristers, physicians, surgeons, solicitors, and scholars among the Catholics themselves. They must not relax their pressure nor relinquish their demands. For their spiritual guides live so exclusively in the pre-scientific past, that even the really strong intellects among them are reduced to atrophy as regards scientific truth. Eyes they have, and see not; ears they have, and hear not; for both eyes and ears are taken possession of by the sights and sounds of another age. In relation to Science, the Ultramontane brain, through lack of exercise, is virtually the undeveloped brain of the child. And thus it is that as children in scientific knowledge, but as potent wielders of spiritual power among the ignorant, they countenance and enforce practices sufficient to bring the blush of shame to the cheeks of the more intelligent among themselves.

Such is the force of early education, when maintained and perpetuated by the habits of subsequent life; such the ground of peril in allowing the schools of a nation to fall into Ultramontane hands. Let any able Catholic student, fairly educated, and not yet cramped by sacerdotalism, get a real scientific grasp of the magnitude and organisation of this universe. Let him sit under the immeasurable heavens, watch the stars in their courses, scan the mysterious nebulæ, and try to realise what it all is and means. Let him bring the thoughts and conceptions which thus enter his mind face to face with the notions of the genesis and rule of things which pervade the writings of the princes of his Church, and he will see and feel what drivellers even men of strenuous intellects may become, through exclusively dwelling and dealing with theological chimeras.

But, quitting the more grotesque forms of the Theological, I already see, or think I see, emerging from recent discussions, that wonderful plasticity of the Theistic Idea which enables it to maintain, through many changes, its hold upon superior minds; and which, if it is to last, will eventually enable it to shape itself in accordance with scientific conditions. I notice this, for instance, in the philosophic sermon of Dr. Quarry, and more markedly still in that of Dr. Ryder. 'There pervades,' says the Rector of Donnybrook, 'these atoms and that illimitable universe, that "choir of heaven and furniture of earth," which of such atoms is built up, a certain *force*, known in its most familiar form by the name of "life," *which may be regarded as the ultimate essence of matter*.' And, speaking of the awful search of the intellect for the infinite Creator, and of the grave difficulties which encompass the subject, the same writer says: 'We know from our senses finite existences only. Now we cannot *logically* infer the existence of an infinite God from the greatest conceivable number of finite existences. There must always obviously be more in the conclusion than in the premisses.' Such language is new to the pulpit, but it will become less and less rare. It is not the poets and philosophers among our theologians—and in our day the philosopher who wanders beyond the strict boundary of Science is more or less merged in the poet—it is not these, who feel the life of religion, but the mechanics, who cling to its scaffolding, that are most anxious to tie the world down to the untenable conceptions of an uncultivated past.

Before me is another printed sermon of a different character from those just referred to. It is entitled 'The Necessary Limits of Christian Evidences.' Its author, Dr. Reichel, has been frequently referred to as an authority, particularly on personal subjects, during recent discussions. The sermon was first preached in Belfast, and afterwards, in an amplified and amended form, in the Exhibition Building in Dublin. In passing, I would make a single remark upon its opening paragraph. This contains an argument regarding Christ which I have frequently heard used in substance by good men, though never before with the grating emphasis here employed. 'The resurrection of our Saviour,' says Dr. Reichel, 'is the central fact of Christianity. Without His resurrection, His birth and His death would have been alike unavailing; nay more, if He did not rise from the dead, His birth was the birth of a bastard, and His death the death of an impostor.' This may be 'orthodoxy;' but entertaining the notions that I do of Christ, and of His incomparable life upon the earth, if the momentary use of the term 'blasphemy' were granted to me by my Christian brethren, I should feel inclined to employ it here.

Better instructed than he had been at Belfast, the orator in Dublin gave prominence to a personal argument which I have noticed elsewhere.[1] He has been

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[1] 'Apology for Belfast Address.'

thus propounded [in Belfast]. An
you should be unduly impressed by
of its propounder, as well as by th
which he sets it forth, it is right
you, that these conclusions, though gi
sion which apparently stamped them
approbation of the scientific world,
approbation. The mind that arrived
played them with so much complacency
in the school of mere experiment, not
in the laboratory. Accordingly the hig
intellects of the Association disclaim
theories of its President. In the mat
which all material phenomena and su
year more distinctly perceived to be
see another side of Nature, which has n
upon the mere experimentalist.' [1]

In view of the new virtue here
mathematician, D'Alembert and Lapla
culty, and we are left without a clu
orthodoxy of Helmholtz, Clifford, and o
men. As regards my own mental

the laboratory *is* a 'study' in which symbols give place to natural facts. The word Mesopotamia is said to have a sacred unction for many minds, and possibly the title of my 'Inaugural Dissertation' at Marburg may have an effect of this kind on my right reverend and reverend critics of the new mathematical school. Here accordingly it is: 'Die Schraubenfläche mit geneigter Erzeugungslinie, und die Bedingungen des Gleichgewichts auf solchen Schrauben.' A little tenderness may, perhaps, flow towards me, after these words have made it known that I began my narrow scientific life less as an experimentalist than as a mathematician.

If, as asserted, 'the highest mathematical intellects of the Association disclaim and repudiate the theories of its President,' it would be their bounden duty not to rest content with this mere second-hand utterance. They ought to permit the light of life to stream upon us directly from themselves, instead of sending it through the rude polemoscope[1] of Dr. Reichel. But the point of importance to be impressed upon him, and upon those who may be tempted to follow him in his adventurous theories, is, that out of Mathematics no salvation for Theology can possibly come.

By such reflections I am brought face to face with an essay to which my attention has been directed by several estimable, and indeed eminent, persons, as demanding serious consideration at my hands. I refer with pleasure to the accord subsisting between the Rev. James Martineau and myself on certain points of biblical Cosmogony. 'In so far,' says Mr. Martineau, 'as Church belief is still committed to a given Cosmogony and natural history of man, it lies open to scientific refutation.' And again: 'It turns out that with the sun and moon and stars, and in and on the earth, before and after the appearance of our race, quite other things have happened than those which the sacred Cosmogony recites.' Once more: 'The whole history of the genesis of things Religion must surrender to the Sciences.' Finally, still more emphatically: 'In the investigation of the genetic order of things, Theology is an intruder, and must stand aside.' This expresses, only in words of fuller pith, the views which I ventured to enunciate in Belfast. 'The impregnable position of Science,' I there say, 'may be stated in a few words. We claim, and we shall wrest from Theology, the entire domain of Cosmological theory.' Thus Theology, so far as it is represented by Mr. Martineau, and Science, so far as I understand it, are in absolute harmony here.

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[1] 'An oblique perspective glass, for seeing objects not directly before the eyes.'—*Webster*. To mere obliquity, Dr. Reichel's instrument adds coarseness of construction.

But Mr. Martineau would have just reason to complain of me, if, by partial citation, I left my readers under the impression that the agreement between us is complete. At the opening of the eighty-ninth Session of the Manchester New College, London, on October 6, 1874, he, its principal, delivered the Address from which I have quoted. It bears the title 'Religion as affected by Modern Materialism;' and its references and general tone make evident the depth of its author's discontent with my previous deliverance at Belfast. I find it difficult to grapple with the exact grounds of this discontent. Indeed, logically considered, the impression left upon my mind by an essay of great æsthetic merit, containing many passages of exceeding beauty, and many sentiments which none but the pure in heart could utter as they are uttered here, is vague and unsatisfactory. The author appears at times so brave and liberal, at times so timid and captious, and at times so imperfectly informed regarding position he assails.

At the outset of his Address Mr. Martineau states with some distinctness his 'sources of religious faith.' They are two—'the scrutiny of Nature' and 'the interpretation of Sacred Books.' It would have been a theme worthy of his intelligence to have deduced from these two sources his religion as it stands. But not another word is said about the 'Sacred Books.' Having swept with the besom of Science various 'books' contemptuously away, he does not define the Sacred residue; much less give us the reasons why he deems them sacred. His references to 'Nature,' on the other hand, are magnificent tirades against Nature, intended, apparently, to show the wholly abominable character of man's antecedents if the theory of evolution be true. Here also his mood lacks steadiness. While joyfully accepting, at one place, 'the widening space, the deepening vistas of time, the detected marvels of physiological structure, and the rapid filling-in of the missing links in the chain of organic life,' he falls, at another, into lamentation and mourning over the very theory which renders 'organic life' 'a chain.' He claims the largest liberality for his sect, and avows its contempt for the dangers of possible discovery. But immediately afterwards he damages the claim, and ruins all confidence in the avowal. He professes sympathy with modern Science, and almost in the same breath he treats, or certainly will be understood to treat, the Atomic Theory, and the doctrine of the Conservation of Energy, as if they were a kind of scientific thimble-riggery.

His ardour, moreover, renders him inaccurate; causing him to see discord between scientific men, where nothing but harmony reigns. In his celebrated Address to the Congress of German Naturforscher, delivered at Leipzig, three years ago, Du Bois Reymond speaks thus: 'What conceivable connection subsists between definite movements of definite atoms in my brain, on the one hand,

and on the other hand such primordial, indefinable, undeniable, facts as these: I feel pain or pleasure; I experience a sweet taste, or smell a rose, or hear an organ, or see something red. . . . It is absolutely and for ever inconceivable that a number of carbon, hydrogen, nitrogen, and oxygen atoms should be otherwise than indifferent as to their own position and motion, past, present, or future. It is utterly inconceivable how consciousness should result from their joint action.'

This language, which was spoken in 1872, Mr. Martineau 'freely' translates, and quotes against me. The act is due to a misapprehension of his own. Evidence is at hand to prove that I employed the same language twenty years ago. It is to be found in the 'Saturday Review' for 1860; but a sufficient illustration of the agreement between my friend Du Bois Reymond and myself, is furnished by the discourse on 'Scientific Materialism,' delivered in 1868, then widely circulated, and reprinted here. With a little attention, Mr. Martineau would have seen that in the very Address his essay criticises, precisely the same position is maintained. 'You cannot,' I there say, 'satisfy the human understanding in its demand for logical continuity between molecular processes and the phenomena of consciousness. This is a rock on which materialism must inevitably split whenever it pretends to be a complete philosophy of the human mind.'

'The affluence of illustration,' writes an able and sympathetic reviewer of this essay, in the 'New York Tribune,' 'in which Mr. Martineau delights often impairs the distinctness of his statements by diverting the attention of the reader from the essential points of his discussion to the beauty of his imagery, and thus diminishes their power of conviction.' To the beauties here referred to I bear willing testimony; but the excesses touched upon reach far beyond the reader, to their primal seat and source in Mr. Martineau's own mind; mixing together *there* things that ought to be kept apart; producing vagueness where precision is the one thing needful; poetic fervour where we require judicial calm; and practical unfairness where the strictest justice ought to be, and I willingly believe is meant to be, observed.

In one of his nobler passages Mr. Martineau tells us how the pupils of his college have been educated hitherto: 'They have been trained under the assumptions (1st) that the Universe which includes us and folds us round is the life-dwelling of an Eternal Mind; (2nd) that the world of our abode is the scene of a moral government, incipient but not complete; and (3rd) that the upper zones of human affection, above the clouds of self and passion, take us into the sphere of a Divine Communion. Into this over-arching scene it is that growing thought and enthusiasm have expanded to catch their light and fire.'

Alpine summits must kindle above the mountaineer who reads these stirring words; I see their beauty and feel their life. Nay, in my own feeble way, at the close of one of the essays here printed, I thus affirm the 'Communion' which Mr. Martineau calls 'Divine': '"Two things," said Immanuel Kant, "fill me with awe—the starry heavens, and the sense of moral responsibility in man." And in his hours of health and strength and sanity, when the stroke of action has ceased, and the pause of reflection has set in, the scientific investigator finds himself overshadowed by the same awe. Breaking contact with the hampering details of earth, it associates him with a power which gives fulness and tone to his existence, but which he can neither analyse nor comprehend.'[1]

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[1] In the first Preface to the 'Belfast Address' I referred to 'hours of

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core of his emotions.

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Mill. But in the light of Mill'
honour, purity, having 'shrunk
subjective susceptibilities, have
Omniscient approval, and all pre
the reality of things.' If Mr. M
any inkling of the process by wh
jective susceptibilities' objectiv
an objective ground of 'Omni
tude from his pupils would hav
But, as it is, he leaves them lost
words, after exciting a desire wh
appease.

'We are,' he says, in another
our representations of

to be seen, or to pass from a divine hue of thinking into a human pattern of thought.' This is very beautiful, and mainly so because the man who utters it obviously brings it all out of the treasury of his own heart. But the 'hue' and 'pattern' here so finely spoken of, are neither more nor less than that 'emotion,' on the one hand, and that 'objective knowledge,' on the other, which have drawn this suicidal fire from Mr. Martineau's battery.

I now come to one of the most serious portions of Mr. Martineau's pamphlet—serious far less on account of its 'personal errors,' than of its intrinsic gravity, though its author has thought fit to give it a witty and sarcastic tone. He analyses and criticises 'the materialist doctrine, which, in our time, is proclaimed with so much pomp, and resisted with so much passion. "Matter is all I want," says the physicist; "give me its atoms alone, and I will explain the universe."' It is thought, even by Mr. Martineau's intimate friends, that in this pamphlet he is answering me. I must therefore ask the reader to contrast the foregoing travesty with what I really do say regarding atoms: 'I do not think that he [the materialist] is entitled to say that his molecular groupings and motions *explain* everything. In reality, they explain nothing. The utmost he can affirm is the association of two classes of phenomena, of whose real bond of union he is in absolute ignorance.'[1] This is very different from saying, 'Give me its atoms alone, and I will explain the universe.' Mr. Martineau continues his dialogue with the physicist: '"Good," he says; "take as many atoms as you please. See that they have all that is requisite to Body [a metaphysical B], being homogeneous extended solids." "That is not enough," he replies; "it might do for

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[1] Address on 'Scientific Materialism.'

Democritus and the mathematicians. but I must have something more. The atoms must not only be in motion, and of various shapes, but also of as many kinds as there are chemical elements; for how could I ever get water if I had only hydrogen elements to work with?" "So be it," Mr. Martineau consents to reply, "only this is a considerable enlargement of your specified datum [where, and by whom specified?]—in fact, a conversion of it into several; yet, even at the cost of its monism [put into it by Mr. Martineau] your scheme seems hardly to gain its end; for by what manipulation of your resources will you, for example, educe Consciousness?"'

This reads like pleasantry, but it deals with serious things. For the last seven years the question proposed by Mr. Martineau and my answer to it have been accessible to all. They are also given in this volume. Here, briefly, is the question: 'A man can say, "I feel, I think, I love," but how does consciousness infuse itself into the problem?' And here is the answer: 'The passage from the physics of the brain to the corresponding facts of consciousness is unthinkable. Granted that a definite thought and a definite molecular action in the brain occur simultaneously; we do not possess the intellectual organ, nor apparently any rudiment of the organ, which would enable us to pass, by a process of reasoning, from the one to the other. They appear together, but we do not know why. Were our minds and senses so expanded, strengthened, and illuminated, as to enable us to see and feel the very molecules of the brain; were we capable of following all their motions, all their groupings, all their electric discharges, if such there be; and were we intimately acquainted with the corresponding states of thought and feeling, we should be as far as ever from the solution of the problem, "How are these physical processes connected with the facts of consciousness?" The chasm between the two classes of phenomena would still remain intellectually impassable.'[1]

Compare this with the answer which Mr. Martineau puts into the mouth of *his* physicist, and with which I am generally credited by Mr. Martineau's readers: '"It [the problem of consciousness] does not daunt me at all. Of course you understand that all along my atoms have been affected by gravitation and polarity; and now I have only to insist with Fechner on a difference among molecules: there are the *inorganic*, which can change only their *place*, like the particles in an undulation; and there are the *organic*, which can change *their order*, as in a globule that turns itself inside out. With an adequate number of these, our problem will be manageable." "Likely enough," we may say [" entirely unlikely," say I], "seeing how careful you are to provide for all emergencies; and if any hitch should occur in the next step, where you will have to pass from mere sentiency to thought and will, you can again look in upon your atoms, and fling among them a handful of Leibnitz's monads, to serve as souls in little, and be ready, in a latent form, with that Vorstellungsfähigkeit which our picturesque interpreters of nature so much prize."'

'But surely,' continues Mr. Martineau, 'you must observe that this "matter" of yours alters its style with every change of service: starting as a beggar, with scarce a rag of "property" to cover its bones, it turns up as a prince when large undertakings are wanted. "We must radically change our notions of matter," says Professor Tyndall; and then, he ventures to believe, it will answer all demands, carrying "the promise and potency of all terrestrial life." If the measure of the required "change in our notions" had been specified, the proposition would have had a real meaning, and been susceptible of a test. It is easy travelling through the stages of such an hypothesis; you deposit at your bank a round sum ere you start, and, drawing on it piecemeal at every pause, complete your grand tour without a debt.'

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[1] Bishop Butler's reply to the Lucretian in the 'Belfast Address' is all in the same strain.

The last paragraph of this argument is forcibly and ably stated. On it I am willing to try conclusions with Mr. Martineau. I may say, in passing, that I share his contempt for the picturesque interpretation of nature, if accuracy of vision be thereby impaired. But the term Vorstellungs-fähigkeit, as used by me, means the power of definite mental presentation, of attaching to words the corresponding objects of thought, and of seeing these in their proper relations, without the interior haze and soft penumbral borders which the theologian loves. To this mode of 'interpreting nature' I shall to the best of my ability now adhere.

Neither of us, I trust, will be afraid or ashamed to begin at the alphabet of this question. Our first effort must be to understand each other, and this mutual understanding can only be ensured by beginning low down. Physically speaking, however, we need not go below the sea-level. Let us then travel in company to the Caribbean Sea, and halt upon the heated water. What is that sea, and what is the sun which heats it? Answering for myself, I say that they are both *matter*. I fill a glass with the sea-water and expose it on the deck of the vessel; after some time the liquid has all disappeared, and left a solid residue of salts in the glass behind. We have mobility, invisibility—apparent annihilation. In virtue of

> The glad and secret aid
> The sun unto the ocean paid,

the water has taken to itself wings and flown off as vapour. From the whole surface of the Caribbean Sea such vapour is rising: and now we must follow it—not upon our legs, however, nor in a ship, nor even in a balloon, but by the mind's eye—in other words, by that power of Vorstellung which Mr. Martineau knows so well, and which he so justly scorns when it indulges in loose practices.

Compounding, then, the northward motion of the vapour with the earth's axial rotation, we track our fugitive through the higher atmospheric regions, obliquely across the Atlantic Ocean to Western Europe, and on to our familiar Alps. Here another wonderful metamorphosis occurs. Floating on the cold calm air, and in presence of the cold firmament, the vapour condenses, not only to particles of water, but to particles of crystalline water. These coalesce to stars of snow, which fall upon the mountains in forms so exquisite that, when first seen, they never fail to excite rapture. As to beauty, indeed, they put the work of the lapidary to shame, while as to accuracy they render concrete the abstractions of the geometer. Are these crystals 'matter'? Without presuming to dogmatise, I answer for myself in the affirmative.

Still, a *formative power* has obviously here come into play which did not manifest itself in either the liquid or the vapour. The question now is, Was not the power 'potential' in both of them, requiring only the proper conditions of temperature to bring it into action? Again I answer for myself in the affirmative. I am, however, quite willing to discuss with Mr. Martineau the alternative hypothesis, that an imponderable formative soul unites itself with the substance after its escape from the liquid state. If he should espouse this hypothesis, then I should demand of him an immediate exercise of that Vorstellungs-fähigkeit, with which, in my efforts to think clearly, I can never dispense. I should ask, At what moment did the soul come in? Did it enter at once or by degrees·

perfect from the first, or growing and perfecting itself contemporaneously with its own handiwork? I should also ask whether it is localised or diffused? Does it move about as a lonely builder, putting the bits of solid water in their places as soon as the proper temperature has set in? or is it distributed through the entire mass of the crystal? If the latter, then the soul has the shape of the crystal; but if the former, then I should enquire after its shape. Has it legs or arms? If not, I would ask it to be made clear to me how a thing without these appliances can act so perfectly the part of a builder? (I insist on definition, and ask unusual questions, if haply I might thereby banish unmeaning words.) What were the condition and residence of the soul before it joined the crystal? What becomes of it when the crystal is dissolved? Why should a particular temperature be needed before it can exercise its vocation? Finally, is the problem before us in any way simplified by the assumption of its existence? I think it probable that, after a full discussion of the question, Mr. Martineau would agree with me in ascribing the building power displayed in the crystal to the bits of water themselves. At all events, I should count upon his sympathy so far as to believe that he would consider any one unmannerly who would denounce me for rejecting this notion of a separate soul, and for holding the snow-crystal to be 'matter.'

But then what an astonishing addition is here made to the powers of matter! Who would have dreamt, without actually seeing its work, that such a power was locked up in a drop of water? All that we needed to make the action of the *liquid* intelligible was the assumption of Mr. Martineau's 'homogeneous extended atomic solids,' smoothly gliding over one another. But had we supposed the water to be nothing more than this, we should have ignorantly defrauded it of an intrinsic architectural power, which the art of man, even when pushed to its utmost degree of refinement, is incompetent to imitate. I would invite Mr. Martineau to consider how inappropriate his figure of a fictitious bank deposit becomes under these circumstances. The 'account current' of matter receives nothing at my hands which could be honestly kept back from it. If, then, 'Democritus and the mathematicians' so defined matter as to exclude the powers here proved to belong to it, they were clearly wrong, and Mr. Martineau, instead of twitting me with my departure from them, ought rather to applaud me for correcting them.

The reader of my small contributions to the literature which deals with the overlapping margins of Science and Theology, will have noticed how frequently I quote Mr. Emerson. I do so mainly because in him we have a poet and a profoundly religious man, who is really and entirely undaunted by the discoveries of Science, past, present, or prospective. In his case Poetry, with the joy of a bacchanal, takes her graver brother Science by the hand, and cheers him with immortal laughter. By Emerson scientific conceptions are continually transmuted into the finer forms and warmer hues of an ideal world. Our present theme is touched upon in the lines—

> The journeying atoms, primordial wholes
> Firmly draw, firmly drive by their animate poles.

As regards veracity and insight these few words outweigh, in my estimation, all the formal learning expended by Mr. Martineau in these disquisitions on Force, in which he treats the physicist as a conjuror, and speaks so wittily of atomic polarity. In fact, without this notion of polarity —this 'drawing' and 'driving'—this attraction and repulsion, we stand as stupidly dumb before the phenomena of Crystallisation as a Bushman before the phenomena of the Solar System. The genesis and growth of the notion

I have endeavoured to make clear in my third Lecture on Light, and in the article 'Crystals and Molecular Force' published in this volume.

Our further course is here foreshadowed. A Sunday or two ago I stood under an oak planted by Sir John Moore, the hero of Corunna. On the ground near the tree little oaklets were successfully fighting for life with the surrounding vegetation. The acorns had dropped into the friendly soil, and this was the result of their interaction. What is the acorn? what the earth? and what the sun, without whose heat and light the tree could not become a tree, however rich the soil, and however healthy the seed? I answer for myself as before—all 'matter.' And the heat and light which here play so potent a part are acknowledged to be motions of matter. By taking something much lower down in the vegetable kingdom than the oak, we might approach much more nearly to the case of crystallisation already discussed; but this is not now necessary.

If, instead of conceding the sufficiency of matter here, Mr. Martineau should fly to the hypothesis of a vegetative soul, all the questions before asked in relation to the snow-star become pertinent. I would invite him to go over them one by one, and consider what replies he will make to them. He may retort by asking me, 'Who infused the principle of life into the tree?' I say, in answer, that our present question is not this, but another—not who made the tree, but what *is* it? Is there anything besides matter in the tree? If so, what, and where? Mr. Martineau may have begun by this time to discern that it is not 'picturesqueness,' but cold precision, that my Vorstellungs-fähigkeit demands. How, I would ask, is this vegetative soul to be presented to the mind? where did it flourish before the tree grew? and what will become of it when the tree is sawn into planks, or consumed in fire?

Possibly Mr. Martineau may consider the assumption of this soul to be as untenable and as useless as I do. But then if the power to build a tree be conceded to pure matter, what an amazing expansion of our notions of the 'potency of matter' is implied in the concession! Think of the acorn, of the earth, and of the solar light and heat—was ever such necromancy dreamt of as the production of that massive trunk, those swaying boughs and whispering leaves, from the interaction of these three factors? In this interaction, moreover, consists what we call *life*. It will be seen that I am not in the least insensible to the wonder of the tree; nay, I should not be surprised if, in the presence of this wonder, I feel more perplexed and overwhelmed than Mr. Martineau himself.

Consider it for a moment. There is an experiment, first made by Wheatstone, where the music of a piano is transferred from its sound-board, through a thin wooden rod, across several silent rooms in succession, and poured out at a distance from the instrument. The strings of the piano vibrate, not singly, but ten at a time. Every string subdivides, yielding not one note, but a dozen. All these vibrations and subvibrations are crowded together into a bit of deal not more than a quarter of a square inch in section. Yet no note is lost. Each vibration asserts its individual rights; and all are, at last, shaken forth into the air by a second sound-board, against which the distant end of the rod presses. Thought ends in amazement when it seeks to realise the motions of that rod as the music flows through it. I turn to my tree and observe its roots, its trunk, its branches, and its leaves. As the rod conveys the music, and yields it up to the distant air, so does the trunk convey the matter and the motion—the shocks and pulses and other vital actions—which eventually emerge in the umbrageous foliage of the tree. I went some time ago through the greenhouse of a friend. He had ferns from Ceylon, the branches of which were in some cases not much thicker than an ordinary pin—hard, smooth, and cylindrical—often leafless for a foot and more. But at the end of every one of them the unsightly twig unlocked the exuberant beauty hidden within it, and broke forth into a mass of fronds, almost large enough to fill the arms. We stand here upon a higher level of the wonderful: we are conscious of a music subtler than that of the piano, passing unheard through these tiny boughs, and issuing in what Mr. Martineau would opulently call the 'clustered magnificence' of the leaves. Does it lessen my amazement to know that every cluster, and every leaf—their form and texture—lie, like the music in the rod, in the molecular structure of these apparently insignificant stems? Not so. Mr. Martineau weeps for 'the beauty of the flower fading into a necessity.' I care not whether it comes to me through necessity or through freedom, my delight in it is all the same. I see what he sees with a wonder superadded. To me as to him—nay, to me more than to him—not even Solomon in all his glory was arrayed like one of these.

I have spoken above as if the assumption of a soul would save Mr. Martineau from the inconsistency of crediting pure matter with the astonishing building power displayed in crystals and trees. This, however, would not be the necessary result; for it would remain to be proved that the soul assumed is not itself matter. When a boy I learnt from Dr. Watts that the souls of conscious brutes are mere matter. And the man who would claim for matter the human soul itself, would find himself in very orthodox company. 'All that is created,' says Fauste, a famous French bishop of the fifth century, 'is matter. The soul occupies a place; it is enclosed in a body; it quits the body at death, and returns to it at the resurrection, as in the case of Lazarus; the distinction between Hell and Heaven, between eternal pleasures and eternal pains, proves that, even after death, souls occupy a place and are corporeal. God only is incorporeal.' Tertullian, moreover, was quite a physicist in the definiteness of his conceptions regarding the soul. 'The materiality of the soul,' he says, 'is evident from the evangelists. A human soul is there expressly pictured as suffering in hell; it is placed in the middle of a flame, its tongue feels a cruel agony, and it implores a drop of water at the hands of a happier soul. *Wanting materiality*,' adds Tertullian, '*all this would be without meaning*.' One wonders what would have happened to this great Christian Father amid the roaring lions of Belfast. Could its excellent press have shielded him from its angry pulpits as it sheltered me? [1]

I have glanced at inorganic nature—at the sea, and the sun, and the vapour, and the snowflake, and at organic nature as represented by the fern and the oak. That same sun which warmed the water and liberated the vapour, exerts a subtler power on the nutriment of the tree. It takes hold of matter wholly unfit for the purposes of nutrition, separates its nutritive from its non-nutritive portions, gives the former to the vegetable, and carries the others away. Planted in the earth, bathed by the air, and tended by the sun, the tree is traversed by its sap, the cells are formed, the woody fibre is spun, and the whole is woven to a texture wonderful even to the naked eye, but a million-fold more so to microscopic vision. Does consciousness mix in any way with these processes? No man can tell. Our only ground for a negative conclusion is the absence of those outward manifestations from which feeling is usually inferred. But even these are not entirely absent. In the greenhouses of Kew we may see that a leaf can close, in response to a proper stimulus, as promptly as the human fingers themselves; and while there Dr. Hooker will tell us of the wondrous fly-catching and fly-devouring power of the Dionæa. No man can say that the feelings of the animal are not represented by a drowsier consciousness in the vegetable world. At all events, no line has ever been drawn between the conscious and the unconscious; for the vegetable shades into the animal by such fine gradations, that it is impossible to say where the one ends and the other begins.

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[1] The foregoing extracts, which M. Alglave recently brought to light for the benefit of the Bishop of Orleans, are taken from the sixth Lecture of the 'Cours d'Histoire Moderne' of that most orthodox of statesmen, M. Guizot. 'I could multiply,' continues M. Guizot, 'these citations to infinity, and they prove that in the first centuries of our era the materiality of the soul was an opinion not only permitted, but dominant.' Dr. Moriarty, and the synod which he recently addressed, obviously forget their own antecedents. Their boasted succession from the early Church renders them the direct offspring of a 'materialism' more 'brutal' than any ever enunciated by me.

In all such enquiries we are necessarily limited by our own powers: we observe what our senses, armed with the aids furnished by Science, enable us to observe; nothing more. The evidences as to consciousness in the vegetable world depend wholly upon our capacity to observe and weigh them. Alter the capacity, and the evidence would alter too. Would that which to us is a total absence of any manifestation of consciousness be the same to a being with our capacities indefinitely multiplied? To such a being I can imagine not only the vegetable, but the mineral world, responsive to the proper irritants, the response differing only in degree from those exaggerated manifestations, which, in virtue of their grossness, appeal to our weak powers of observation.

Our conclusions, however, must be based, not on powers that we can imagine, but upon those that we possess. What do they reveal? As the earth and atmosphere offer themselves as the nutriment of the vegetable world, so does the latter, which contains no constituent not found in inorganic nature, offer itself to the animal world.

Mixed with certain inorganic substances—water, for example—the vegetable constitutes, in the long run, the sole sustenance of the animal. Animals may be divided into two classes, the first of which can utilise the vegetable world immediately, having chemical forces strong enough to cope with its most refractory parts; the second class use the vegetable world mediately; that is to say, after its finer portions have been extracted and stored up by the first. But in neither class have we an atom newly created. The animal world is, so to say, a distillation through the vegetable world from inorganic nature.

From this point of view all three worlds would constitute a unity, in which I picture life as immanent everywhere. Nor am I anxious to shut out the idea that the life here spoken of, may be but a subordinate part and function of a Higher Life, as the living, moving blood is subordinate to the living man. I resist no such idea as long as it is not dogmatically imposed. Left for the human mind freely to operate upon, the idea has ethical vitality; but, stiffened into a dogma, the inner force disappears, and the outward yoke of a usurping hierarchy takes its place.

The problem before us is, at all events, capable of definite statement. We have on the one hand strong grounds for concluding that the earth was once a molten mass. We now find it not only swathed by an atmosphere, and covered by a sea, but also crowded with living things. The question is, How were they introduced? Certainty may be as unattainable here as Bishop Butler held it to be in matters of religion; but in the contemplation of probabilities the thoughtful mind is forced to take a side. The conclusion of Science, which recognises unbroken causal connection between the past and the present, would undoubtedly be that the molten earth contained within it elements of life, which grouped themselves into their present forms as the planet cooled. The difficulty and reluctance encountered by this conception, arise solely from the fact that the theologic conception obtained a prior footing in the human mind. Did the latter depend upon reasoning alone, it could not hold its ground for an hour against its rival. But it is warmed into life and strength by associated hopes, fears, and expectations—and not only by these, which are more or less mean, but by that loftiness of thought and feeling which lifts its possessor above the atmosphere of self, and which the theologic idea, in its nobler forms, has through ages engendered in noble minds.

Were not man's origin implicated, we should accept without a murmur the derivation of animal and vegetable life from what we call inorganic nature. The conclusion of pure intellect points this way and no other. But this purity is troubled by our interests in this life, and by our hopes and fears regarding the life to come. Reason is traversed by the emotions, anger rising in the weaker heads to the height of suggesting that the compendious shooting of the enquirer would be an act agreeable to God and serviceable to man. But this foolishness is more than neutralised by the sympathy of the wise; and in England at least, so long as the courtesy which befits an earnest theme is adhered to, such sympathy is ever ready for an honest man. None of us here need shrink from saying all that he has a right to say. We ought, however, to remember that it is not only a band of Jesuits, weaving their schemes of intellectual slavery, under the innocent guise of 'education,' that we are opposing. Our foes are to some extent they of our own household, including not only the ignorant and the passionate, but a minority of minds of high calibre and culture, lovers of freedom, moreover, who, though its objective hull be riddled by logic, still find the ethic life of their religion unimpaired. But while such considerations ought to influence the *form* of our argument, and prevent it from ever slipping out of the region of courtesy into that of scorn or abuse, its *substance*, I think, ought to be maintained and presented in unmitigated strength.

In the year 1855 the chair of philosophy in the University of Munich happened to be filled by a Catholic priest of great critical penetration, great learning, and great courage, who bore the brunt of battle long before Döllinger. His Jesuit colleagues, he knew, inculcated the belief that every human soul is sent into the world from God by a separate and supernatural act of creation. In a work entitled 'The Origin of the Human Soul,' Professor Frohschammer, the philosopher here alluded to, was hardy enough to question this doctrine, and to affirm that man, body and soul, comes from his parents, the act of creation being, therefore, mediate and secondary only. The Jesuits keep a sharp look out on all temerities of this kind, and their organ, the 'Civiltà Cattolica,' immediately pounced upon Frohschammer. His book was branded as 'pestilent,' placed in the Index, and stamped with the condemnation of the Church.[1]

It will be seen in the 'Apology for the Belfast Address' how simply and beautifully the great Jesuit Perrone causes the Almighty to play with the sun and planets, desiring this one to stop, and another to move, according to His pleasure. To Perrone's Vorstellung God is obviously a large Individual who holds the leading-strings of the Universe, and orders its steps from a position outside it all. Nor does the notion now under consideration err on the score of indefiniteness. According to it, the Power whom Goethe does not dare to name, and whom Gassendi and Clerk Maxwell present to us under the guise of a 'Manufacturer' of atoms, turns out annually, for England and Wales alone, a quarter of a million of new souls. Taken in connection with the dictum of Mr. Carlyle, that this annual increment to our population are 'mostly fools,' but little profit to the human heart seems derivable from this mode of regarding the Divine operations.

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[1] King Maximilian II. brought Liebig to Munich, he helped Helmholtz in his researches, and loved to liberate and foster science. But through his liberal concession of power to the Jesuits in the schools, he did far more damage to the intellectual freedom of his country than his superstitious predecessor Ludwig I. Priding himself on being a German prince, Ludwig would not tolerate the interference of the Roman party with the political affairs of Bavaria.

But if the Jesuit notion be rejected, what are we to accept? Physiologists say that every human being comes from an egg, not more than the $\frac{1}{120}$th of an inch in diameter. Is this egg matter? I hold it to be so, as much as the seed of a fern or of an oak. Nine months go to the making of it into a man. Are the additions made during this period of gestation drawn from matter? I think so undoubtedly. If there be anything besides matter in the egg, or in the infant subsequently slumbering in the womb, what is it? The questions already asked with reference to the stars of snow may be here repeated. Mr. Martineau will complain that I am disenchanting the babe of its wonder; but is this the case? I figure it growing in the womb, woven by a something not itself, without conscious participation on the part of either father or mother, and appearing in due time, a living miracle, with all its organs and all their implications. Consider the work accomplished during these nine months in forming the eye alone—with its lens, and its humours, and its miraculous retina behind. Consider the ear with its tympanum, cochlea, and Corti's organ—an instrument of three thousand strings, built adjacent to the brain, and employed by it to sift, separate, and interpret, antecedent to all consciousness, the sonorous tremors of the external world. All this has been accomplished, not only without man's contrivance, but without his knowledge, the secret of his own organisation having been withheld from him since his birth in the immeasurable past, until the other day. Matter I define as that mysterious thing by which all this is accomplished. How it came to have this power is a question on which I never ventured an opinion. If, then, Matter starts as 'a beggar,' it is, in my view, because the Jacobs of theology have deprived it of its birthright. Mr. Martineau need fear no disenchantment. Theories of evolution go but a short way towards the explanation of this mystery; while, in its presence, the notion of an atomic Manufacturer and Artificer of souls raises the doubt, whether those who entertain it were ever really penetrated by the solemnity of the problem for which they offer such a solution.

There are men, and they include amongst them some of the best of the race of men, upon whose minds this mystery falls without producing either warmth or colour. The 'dry light' of the intellect suffices for them, and they live their noble lives untouched by a desire to give the mystery shape or expression. There are, on the other hand, men whose minds are warmed and coloured by its presence, and who, under its stimulus, attain to moral heights which have never been overtopped. Different spiritual climates are necessary for the healthy existence of these two classes of men; and different climates must be accorded them. The history of humanity, however, proves the experience of the second class to illustrate the most pervading need. The world will have religion of some kind, even though it should fly for it to the intellectual whoredom of 'spiritualism.' What is really wanted is the lifting power of an ideal element in human life. But the free play of this power must be preceded by its release from the torn swaddling bands of the past, and from the practical materialism of the present. It is now in danger of being strangled by the one, or stupefied by the other. I look, however, forward to a time when the strength, insight, and elevation which now visit us in mere hints and glimpses during moments 'of clearness and vigour,' shall be the stable and permanent possession of purer and mightier minds than ours—purer and mightier, partly because of their deeper knowledge of matter and their more faithful conformity to its laws.

JOHN TYNDALL.

ATHENÆUM CLUB: *November* 1875.

REFLECTIONS ON PRAYER AND NATURAL LAW.

THE aspects of nature are more varied and impressive in Alpine regions than elsewhere. The mountains in their setting of deep blue sky; the glow of firmament and peaks at sunrise and sunset; the formation and distribution of clouds; the descent of rain, hail, and snow; the stealthy slide of glaciers and the rush of avalanches and rivers; the fury of storms; thunder and lightning, with their occasional accompaniment of blazing woods;—all these things tend to excite the feelings and to bewilder the mind. In this entanglement of phenomena it seems hopeless to seek for law or orderly connection. And before the thought of law dawned upon the human mind, men naturally referred these inexplicable effects to personal agency. In the fall of a cataract the savage saw the leap of a spirit, and the echoed thunder-peal was to him the hammer-clang of an exasperated god. Propitiation of these terrible powers was the consequence, and sacrifice was offered to the demons of earth and air.

But observation tends to chasten the emotions and to check those structural efforts of the intellect which have emotion for their base. One by one natural phenomena have been associated with their proximate causes; and the idea of direct personal volition mixing itself with the economy of nature is retreating more and more. Many of us fear this tendency. Our faith and feelings are dear to us, and we look with suspicion and dislike on any philosophy, the apparent tendency of which is to dry up the soul. Probably every change from ancient savagery to our present enlightenment has excited, in a greater or less degree, a fear of this kind. But the fact is, that we have not yet determined whether its present form is necessary to the life and warmth of religious feeling. We may err in linking the imperishable with the transitory, and confound the living plant with the decaying pole to which it clings. My object, however, at present is not to argue, but to mark a tendency. We have ceased to propitiate the powers of nature—ceased even to pray for things in *manifest* contradiction to natural laws. In Protestant countries, at least, I think it is conceded that the age of miracles is past.

At the auberge near the foot of the Rhone glacier, I met, in the summer of 1858, an athletic young priest, who, after a solid breakfast, including a bottle of wine, informed me that he had come up to 'bless the mountains.' This was the annual custom of the place. Year by year the Highest was entreated, by official intercessors, to make such meteorological arrangements as should ensure food and shelter for the flocks and herds of the Valaisians. A diversion of the Rhone, or a deepening of the river's bed, would, at the time I now mention, have been of incalculable benefit to the inhabitants of the valley. But the priest would have shrunk from the idea of asking the Omnipotent to open a new channel for the river, or to cause a portion of it to flow over the Grimsel pass, and down the vale of Oberhasli to Brientz. This he would have deemed a *miracle*, and he did not come to ask the Creator to perform miracles, but to do something which he manifestly thought lay quite within the bounds of the natural and non-miraculous. A Protestant gentleman who was present at the time smiled at this recital. He had no faith in the priest's blessing; still, he deemed his prayer different in kind from a request to open a new river-cut, or to cause the water to flow up-hill.

In a similar manner self-satisfied Protestants smile at the honest Tyrolese priest, who, when he feared the bursting of a glacier dam, offered the sacrifice of the Mass upon the ice as a means of averting the calamity. That poor man did not expect to convert the ice into adamant, or to strengthen its texture, so as to enable it to withstand the pressure of the water; nor did he expect that his sacrifice would cause the stream to roll back upon its source and relieve him, by a miracle, of its presence. But beyond the boundaries of his knowledge lay a region where rain was generated, he knew not how. He was not so presumptuous as to expect a miracle, but he firmly believed that in yonder cloud-land matters could be so arranged, without trespass on the miraculous, that the stream which threatened him and his flock should be caused to shrink within its proper bounds.

Both these priests fashioned that which they did not understand to their respective wants and wishes. In their case imagination came into play, unconditioned by a knowledge of laws. A similar state of mind was long prevalent among mechanicians. Many of these, and some of them extremely skilful ones, were occupied a century ago with the question of perpetual motion. They aimed at constructing a machine which should execute work without the expenditure of power; and some of them went mad in the pursuit of this object. The faith in such a consummation, involving, as it did, immense personal profit to the inventor, was extremely exciting, and every attempt to destroy this faith was met by bitter resentment on the part of those who held it. Gradually, however, as men became more and more acquainted with the true functions of machinery, the dream dissolved. The hope of getting work out of mere mechanical combinations disappeared, but still there remained for the speculator a cloud-land denser than that which filled the imagination of the Tyrolese priest, out of which he still hoped to evolve perpetual motion. There was the mystic store of chemic force, which nobody understood; there were heat and light, electricity and magnetism, all competent to produce mechanical motions.[1] Here, then, is the mine in which we must seek our gem. A modified and more refined form of the ancient faith revived; and, for aught I know, a remnant of sanguine designers may at the present moment be engaged on the problem which like-minded men in former ages left unsolved.

And why should a perpetual motion, even under modern conditions, be impossible? The answer to this question is the statement of that great generalisation of modern science, which is known under the name of the Conservation of Energy. This principle asserts that no power can make its appearance in nature without an equivalent expenditure of some other power; that natural agents are so related to each other as to be mutually convertible, but that no new agency is created. Light runs into heat; heat into electricity; electricity into magnetism; magnetism into mechanical force; and mechanical force again into light and heat. The Proteus changes, but he is ever the same; and his changes in nature, supposing no miracle to supervene, are the expression, not of spontaneity, but of physical necessity. A perpetual motion, then, is deemed impossible, because it demands the creation of force, whereas the principle of Conservation is—no creation, but infinite conversion.

It is an old remark that the law which moulds a tear also rounds a planet. In the application of law in nature the terms great and small are unknown. Thus the principle referred to teaches us that the Italian wind, gliding over the crest of the Matterhorn, is as firmly ruled as the earth in its orbital revolution round the sun; and that the fall of its vapour into clouds is exactly as much a matter of necessity as the return of the seasons. The dispersion, therefore, of the slightest mist by the special volition of the Eternal, would be as much a miracle as the rolling of the Rhone over the Grimsel precipices, down the valley of Hasli to Meyringen and Brientz.

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[1] See Helmholtz—'Wechselwirkung der Naturkräfte.'

It seems to me quite beyond the present power of science to demonstrate that the Tyrolese priest, or his colleague of the Rhone valley, asked for an 'impossibility' in praying for good weather; but Science *can* demonstrate the incompleteness of the knowledge of nature which limited their prayers to this narrow ground; and she may lessen the number of instances in which we 'ask amiss,' by showing that we sometimes pray for the performance of a miracle when we do not intend it. She does assert, for example, that without a disturbance of natural law, quite as serious as the stoppage of an eclipse, or the rolling of the St. Lawrence up the Falls of Niagara, no act of humiliation, individual or national, could call one shower from heaven, or deflect towards us a single beam of the sun.

Those, therefore, who believe that the miraculous is still active in nature, may, with perfect consistency, join in our periodic prayers for fair weather and for rain: while those who hold that the age of miracles is past, will, if they be consistent, refuse to join in such petitions. And if these latter wish to fall back upon such a justification, they may fairly urge that the latest conclusions of science are in perfect accordance with the doctrine of the Master himself, which manifestly was that the distribution of natural phenomena is not affected by moral or religious causes. 'He maketh His sun to rise on the evil and on the good, and sendeth rain on the just and on the unjust.' Granting 'the power of Free Will in man,' so strongly claimed by Professor Mansel in his admirable defence of the belief in miracles, and assuming the efficacy of free prayer to produce changes in external nature, it necessarily follows that natural laws are more or less at the mercy of man's volition, and no conclusion founded on the assumed permanence of those laws would be worthy of confidence.

It is a wholesome sign for England that she numbers among her clergy men wise enough to understand all this, and courageous enough to act up to their knowledge. Such men do service to public character, by encouraging a manly and intelligent conflict with the real causes of disease and scarcity, instead of a delusive reliance on supernatural aid. But they have also a value beyond this local and temporary one. They prepare the public mind for changes, which though inevitable, could hardly, without such preparation, be wrought without violence. Iron is strong; still, water in crystallising will shiver an iron envelope, and the more unyielding the metal is, the worse for its safety. There are men amongst us who would encompass philosophic speculation by a rigid envelope, hoping thereby to restrain it, but in reality giving it explosive force. If we want an illustration of this we have only to look at modern Rome. In England, thanks to men of the stamp to which I have alluded, scope is gradually given to thought for changes of aggregation, and the envelope slowly alters its form, in accordance with the necessities of the time.

The foregoing remarks were first published in a little book of mine, entitled 'Mountaineering in 1861.' They were prompted by the obloquy incurred by certain ministers of the Church of England, through their refusal to join in an act of humiliation with reference to a bad harvest.[1] Three years after their publication we were threatened by cholera and invaded by the cattle plague. On October 5, 1865, 'an order in Council commanding a special form of prayer for the removal of the cattle plague, and the preservation of the country from cholera,' was issued, and on October 9, the following article on the subject appeared in the 'Pall Mall Gazette':—

PRAYERS AGAINST THE CHOLERA.

It would be affectation to disguise the fact that very many of the more educated English laity look with small favour on the proposal that we should all pray, as a nation, for the warding off of the cholera and the removal of the cattle plague. It is not that they are insensible to the claims of religion, or that they regard the physical universe as a self-acting machine which has gone on with its unconscious life from all eternity, or that they object to praying altogether. Perhaps there never was a time when a sincere recognition of the force of religious obligation was as general among men of learning and profound thought as it is at the present moment. Godlessness is not the characteristic of our time. Its characteristic is an ever-increasing conviction of the uniformity of the operations of all physical law, not as a self-existent necessity, but as a result of the fiat of the Eternal Mind. As a consequence of this supremacy of unchanging law it is held that it is a transparent absurdity to imagine that on the petition of any man or any number of men the operations of natural law will be suspended. To ask of the Almighty God that

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[1] On such notions see quotation from Whewell, page 470.

He would alter the course of the planets, or cause water to flow upwards, would be more startling in its presumptuous imbecility, but it would not be more useless or philosophically more extravagant, than this act of national supplication to which we are now invited. The truth or error of this view is not a fit subject for treatment in a newspaper. By a wise though tacit understanding, journalists for the most part abstain from handling the dogmas of Christianity and of religion in general. But when the Government of the day comes forward with a formal proposal that we should go out of our way to unite in a special religious act under the pressure of a heavy national calamity, it is impossible altogether to ignore the convictions entertained by very many of the ablest and most honest thinkers of the day. There is no necessity, indeed, to treat the question in any way from the dogmatic point of view. If we venture on the subject at all, it is in order to call attention to certain phenomena in our every-day life, which appear to furnish a clue to all the real difficulties of the subject. The facts of the case are so obvious, and the reasoning that they suggest is so simple, that they may be presented in the shortest space.

Certain, then, as it is, that the laws of the material universe are absolutely unchangeable, it is equally certain that they are susceptible of a boundless variety of distinct combinations. Whether all organic forms and all animal and vegetable life are, or are not, the results of the presence of some one hidden universal material agent, in operation the phenomena are the same. The laws of gravity, of chemical affinity, of electric action, of heat, and every other force that is concerned in carrying forward organic change and vegetable and animal life, produce in reality infinite variations of results, according to the conditions under which their powers are called into action. These combinations at one time give birth to the cholera, at another to the cattle plague, at another to rich harvests, at another to famine. These combinations, moreover, are not the result of the boundless varieties of the action of material forces alone. We ourselves imitate these fresh combinations every moment that we live. Human life, in fact, is carried on by means of a perpetual struggle of the human will with the elementary laws of physical action. The actual condition of the material world is totally unlike what it would have been if man had never existed on this globe. We live upon the forms of vegetable and animal life which are created in harmony with physical law, as constrained to yield to our personal control. The chemical condition of the atmosphere is modified by every movement of our lungs, by every fire we light, by every candle we blow out, by every forest we plant, by every field we drain. It is not too much to say that the position of the centre of gravity in the great globe itself can be made to move, in a real, though to us inappreciable degree, by the alterations we work in the form of the earth's surface. The remedies we are now devising for the warding off of the cholera are in reality an intervention with the modes of operation of chemical, atmospherical, and pathological law. We cannot alter these laws in themselves, but by the exercise of our wills we can compel them, like the spirits in Oriental tales coerced by the seal of the mighty Solomon, to yield results not deadly, but life-giving. Thus, then, in a most true and real sense, the great Author of physical law permits us, if we so please to call it, to interfere with the universe as He originally created it. Or rather this incessant interference is the very condition of our own life; and physical law can only be called unchangeable with the proviso that it is to this extent changeable at the dictates of the will of man.

Granting, then, the belief (which we are not called on to argue) that prayer is in its essence a direct intercourse between rational beings and the Author of physical laws, there appears no scientific difficulty in conceiving that, in reply to our solicitation, He might himself institute fresh combinations in their operation of the same nature as those which we ourselves undoubtedly produce every hour that we live. No reasonable person will deny the abstract possibility of the same modifications of the work of law, caused by the direct power of God, which can be accomplished by us. It would, in truth, be ridiculous to doubt it. The supremacy and unchangeableness of law would be in each case untouched. The theory of those who most rigorously deny the possibility of anything wearing the semblance of miraculous interference would not be impugned by a hair's breadth. There is no need to have recourse to the *argumentum ad verecundiam* of the superficially pious, who triumphantly ask us whether the Creator of the universe cannot alter the laws that He himself has made. The men who asked Lord Palmerston for a fast day, and for answer were told to look to their drainage, may learn that the cleansing of sewers and the offering of prayers, though two distinct outward acts, are in reality of a nature essentially the same. What we do 'immediately,' to use the technical term, with our own hands, when we disinfect our houses and attend to our diet, and make experiments in medicine, it is possible we may also do 'mediately,' by entreating of God that He will supplement our ignorant efforts by physical means, which bear the same relation as our own to existing laws, being solely different in that His knowledge of His own laws is complete, while ours is little more than a tentative guesswork.

As we have said, in offering these suggestions we are not meddling with the subject under its more dogmatic aspects. Still less are we paying an instant's heed to the follies of the school that looks upon these newly recurring visitations of old diseases as 'judgments,' or 'punishments,' or as in any sense differing from the ordinary organic routine of animal life as it goes on from day to day and from age to age. It is as irreligious as it is unphilosophical to take the life of a nation or of a man, and map it out into little sections, and call one thing a judgment and another a blessing, and even interpret these judgments and blessings as being specially merited by our neighbour's sins or by our own virtues. Doubtless they are all parts of one mighty whole which we know to be harmonious throughout, but which we also know to be so partially understood that it is absurd to classify its fragments, and ticket them in accordance with the shallow prejudices of the hour. The foolishness of these half-pious and wholly superficial religionists does not consist in their believing that cholera and cattle plagues are of Divine origin, and have a meaning and a bearing on human life in its highest aspects. It consists in their impudent pretence of prophetic gifts, and in the spiritual quackery with which they recommend remedies suggested only by an immeasurable self-complacency. Further, as to this setting apart of a special time for national supplication, we say nothing whatever concerning its wisdom or prudence; and we state this without the slightest *arrière pensée* or reserve. Our aim is solely to look at the question on its scientific side, and to suggest to those who feel acutely the difficulties which perhaps they do not like to avow, a certain solution which appears satisfactory, even to the most tender consciences, and which undoubtedly rests on the undeniable facts of every-day life.

On the day after its publication this article reached my hands, accompanied by a note commending it as a fair reply to my article of 1861. The friend who sent it to me was perfectly orthodox and of high rank among scientific men. I gave it due consideration, and wrote in reference to it the following brief letter to the 'Pall Mall Gazette':—

To the Editor *of the* 'Pall Mall Gazette.'

Sir,—An eminent and respected scientific friend has drawn my attention to your exceedingly clever article entitled 'Prayers against Cholera.' The position there taken is a strong one; for, granting the entire freedom of the human will, that it, unlike natural phenomena, is uncontrolled by its antecedents, it follows that, within certain limits, arbitrary changes may be wrought in the order and sequence of those phenomena. And if the possibility of such changes, even in the smallest particular, be conceded, the abstract possibility, or in other words the *conceivability*, of a change upon a grand scale follows as a matter of course. Hence (you would argue) the petitioning of the Almighty against cholera or cattle plague is rescued from the charge of necessary absurdity.

But you will, I think, admit that the value of this argument is not bounded by the limits of nineteenth century Christendom; that it would apply equally well to the beliefs of ancient heathens and modern savages, who saw and see in almost every change of the aspects of nature the hand of an arbitrary Deity. It justifies equally the mildest and the most extravagant belief in spontaneous interference. Who, indeed, in such a case, is to draw the line between mildness and extravagance? Once upon a time we prayed against the ravages of small-pox—with what effect? You may answer (and rightly answer) that you do not know. But you will, at all events, admit that the prayer, as a preventive or remedial agent, proved no match for vaccination. Would the suppliant voice of a whole nation have atoned for the bad engineering, or [illegible] suspension of the laws of hydraulic pressure, in [illegible] of the Bradfield reservoir? I think not. The great majority of sane persons at the present day believe in the necessary character of natural laws, and it is only where the antecedents of a calamity are vague or disguised that they think of resorting to prayer to avert it. Such unhappily is the case with the cholera and the cattle plague. With regard to them we are in a state of darkness similar to that of the ancient pagan world with regard to natural phenomena generally, and hence the disposition to resort to pagan methods of meeting these scourges.

JOHN TYNDALL.

October 11, 1865.

On October 17 the argument was resumed in a second article by the 'Pall Mall Gazette':—

ON PRAYER AND THE CHOLERA.

We are tempted by Professor Tyndall's letter, which we published on Thursday, to return to the subject of the article which he criticises. He has, we think, partly failed in understanding the drift of our remarks. He attributes to us a belief in the 'entire freedom of the human will' as being 'uncontrolled by its antecedents,' a belief which we certainly neither expressed nor intended to discuss. We neither contrasted the operations of the will with 'natural phenomena,' nor did we attempt any definition of its nature or powers. We simply took the 'human will' as a fact in nature, and pointed out the character of its operations in modifying the combinations of material agencies. That the will itself is subject to its own laws we do not for a moment deny; but that it is 'controlled by its antecedents,' in Professor Tyndall's language, we are very far from admitting. To whatever degree its acts may be affected by its own past history, or by the influence of the past and present knowledge possessed by the understanding, the existence of an apparent real freedom in the will is unquestionably a fact. Whatever be the ultimate character of this freedom, we all of us think we are free, and we act as if we are free. Not, indeed, that we act as if our freedom were absolute. Our freedom is restrained within certain limits. It is limited by the laws of our personal character, by the habits of our past life, and in one man it appears to be far stronger and more independent than in another. But whether it is by the exercise of a certain real freedom of the will that we ventilate our houses and take other precautions against contagion, or whether this freedom is a mere deception under which human nature labours, so that we have no real choice as to what we will or will not do—just as the wheels of a locomotive cannot help being whirled round and round by the force of steam—the physical results are the same. And our argument as to these appointed prayers was based on this simple phenomenon in the organic life of the mental and material universe. Just so far as a man possesses an immediate power over the combinations of material law, just so far it is *possible* that he may be able to influence the actual operations of law by the entreaties he addresses to the Supreme Authority of the universe. We can do much ourselves; and there is no absurdity in holding that it is not impossible that we may do still more through the agency of these prayers.

The second paragraph of Professor Tyndall's letter still further suggests the suspicion that he has not fully entered into the view we put forward. The theory, he says, would apply equally well to the beliefs of ancient heathens and modern savages, who saw and see in almost every change of the aspects of Nature the hand of an arbitrary Deity; and it justifies equally the mildest and the most extravagant belief in spontaneous interferences. By what possible reasoning process are these inferences extracted from our statements? How does the belief that some results may possibly be effected by the agency of prayer lead to the conclusion that we may invariably expect results of gigantic magnitude? What, let us ask, are the results of all human action upon the physical laws of the universe? For one successful result of our efforts are we not baffled a thousand times? It is said that praying is logically absurd, because it is like shooting an arrow into the dark. Nobody knows, and nobody can know, whether it really does any good. But is not the same to be said of almost everything we attempt? What has been the result of all our speculations as to the cause and nature of cholera, and as to the remedies to which it will yield? Nothing, or almost nothing. We have shot our arrows into the dark, and know not where they have fallen. But is that a reason for discontinuing our speculations and experiments? Far from it. How many thousand years have doctors been trying to cure diseases of all kinds? And yet, to this day, what do they know, and what can they do? Are there yet as many as half a dozen really proved 'specifics' for as many complaints? Yet they continue their guessings and experimentalisings, and wisely continue them. The heathen and modern savage knew and know little or nothing of the nature of law, as such; but how does that affect our argument, which is grounded on the recognition of the absolute supremacy of all law? They held and hold that the Eternal Mind acts on caprice, and 'spontaneously interferes' in the government of the world. How does that error dispose of a theory which rests on the hypothesis that God never acts on caprice, and which simply suggests the possibility of an extension of the laws of human action into a sphere where the mind can penetrate, though the hand and the eye are restrained from following it? 'You will admit,' says Mr. Tyndall, 'that prayer, as a preventive or remedial agent, in the case of the small-pox, proved no match for vaccination.' We reply, that we never contrasted them. There never was a race between the two. Vaccination we now know to be a most efficacious preventive; but how does that prove that prayer is necessarily inoperative? For thousands of years mankind knew nothing of the value of vaccination. On Mr. Tyndall's theory of reasoning, it might be alleged that the ignorance of past ages proved that no remedy could possibly, in the nature of things, exist at all. 'Would the suppliant voice of a whole nation have atoned for the bad engineering, or caused a suspension of the laws of hydraulic pressure, in the case of the Bradfield reservoir?' Undoubtedly not. But how does that prove that there can be no possible combinations of physical laws except those which we produce with our arms and hands? A Red Indian might with equal reason conclude that, because he could not make a watch, therefore no human being could make one. 'The great majority of sane persons at the present day,' continues Professor Tyndall, 'believe in the necessary character of natural laws, and it is only where the antecedents of a calamity are vague or disguised that they think of resorting to prayer to avert it.' Undeniably. It is also equally true that the great majority of sane persons do not think of resorting to drainage and ventilation until the cholera has shown itself; but their folly is no disproof of the value of good drains and fresh air. The popular neglect of a remedy does not prove its worthlessness; otherwise, by a parity of reasoning, the popularity of a quack medicine would prove its excellence, and Holloway's Pills would be the one infallible remedy for all our ills. The theory we have attempted, however feebly, to explain, undoubtedly applies to every circumstance of human life. If prayer is the supplement to the labours of our hands, and completes the organic harmony of the entire universe, unquestionably it is absurd to have recourse to it only when we are smitten with a national panic.

Here, indeed, is the ground for an objection to these national acts of supplication. If the Privy Council tell us to pray because the cholera is advancing from east to west, do they not encourage the notion that only great calamities come from God, and that He is a sort of intruder in our proper domain, which in ordinary seasons He leaves altogether to our own management? We do not say that this is an objection which cannot be satisfactorily answered. Nevertheless, just as Sabbatarian rigorism tends to promote week-day godlessness, so these panic-stricken supplications have a tendency to foster that epicureanism in theology to which we are all of us sufficiently disposed.

> When the devil was sick, the devil a saint would be;
> When the devil got well, the devil a saint was he.

To this article I replied on the 19th in the following terms:—

To the EDITOR *of the* 'PALL MALL GAZETTE.'

SIR,—I have read with interest the letters of your correspondents 'E. W.' and 'H. W. W.,' and your own thoughtful second article on the influence of national prayer. It gives me true pleasure to exchange ideas with such earnest men on so important a subject.

In answer to your correspondent 'E. W.' I would first say that when I affirm necessity I merely affirm the result of knowledge and experience. Science shows that certain consequents follow certain antecedents with such undeviating uniformity that the association between antecedent and consequent has become inseparable in thought. We explain the known and predict the unknown on the assumption of this inseparability. On the same ground of experience, the ideas of prayer and of a change in the course of natural phenomena refuse to be connected in thought. I believe that water will wet, that iron will sink in it, that fire will burn, that the sun will rise to-morrow, and hold that no prayer at the present day will alter such facts. Both you and your correspondents probably entertain the same opinion. You do not seem disposed to pray for undoubted miracles. Where the antecedent is perfectly clear, you prepare yourselves for the consequent. Now, as a matter of fact, in cases of national supplication the antecedents are often very clear to one class of the community, though very dark to another and a larger class. This explains the fact, that while the latter are ready to resort to prayer, the former decline doing so. The difference between both classes is one of knowledge, not of religious feeling. I turn to the account of the Epping cholera case, and learn that the people drank poisoned water. To alter, by prayer, the consequences of this or any similar fact—to deprive, by petition, even a single molecule of miasmatic matter of its properties—would in the eye of science be as much a miracle as to make the sun and moon stand still. For one of these results neither of us would pray; on the same grounds I refuse to pray for either.

With regard to the efficacy of prayer, I grant all manner of *possibilities*, or, more correctly, *conceivabilities*. Whenever we have undoubted evidence of the smallest phenomenon, we can, in imagination, expand it to the largest. I jump over a hillock, and can therefore imagine a man jumping over Mont Blanc. Certain bodies are repelled by the poles of a magnet, and I can imagine this force of repulsion so augmented as to urge projectiles in war. But though I can *conceive* both, I *believe* in neither the jumping of the mountain nor the projectile force of diamagnetism. Similarly, a good-natured man grants my request when I ask him for a share of his umbrella. I can, in imagination, expand this fact to the infinite, and ask Omnipotence to ward off the rain from my paddock. That He *may* do so is conceivable, but experience renders it unbelievable. The people of England are already more or less conscious of this; and the practice of national propitiation is, I believe, doomed, which requires the great ability of this journal—not to direct the spontaneous fervour of a smitten and a threatened people to the Throne of Grace—not even to prove that it is the bounden duty of the nation to engage in supplication—but to show that such an act is not intrinsically absurd.

Both your correspondents seem to think that scientific discovery may be a result of a prayer. If this be believed, I will only say that the bearing of theology towards science at the present day is as unpardonable as it is unaccountable.

You speak very frequently of the combinations of material law possible to man. Have you ever analysed these combinations? You stretch forth your arm and move your inkstand. Is this an act of volition pure and simple? It is not. The external motion of your arm is derived immediately from a motion *within* your arm—it *is*, in fact, this motion in another shape. While you were pushing your inkstand a certain amount of oxidation occurred in the muscles of your arm, which oxidation, under normal circumstances, produces a certain definite amount of heat. To move the inkstand, a quantity of that heat has been consumed, which is the exact thermal equivalent of the work done. You could do the same work with the same amount of heat from an ordinary fire. The force employed is the force of your food which is stored up in your muscles. The motor nerves pull the trigger and discharge this force. You have here a series of transformations of purely physical energy with one critical point involved in the question, '*What causes the motor nerves to pull the trigger?*' Is the cause physical or super-physical? Is it a sound or a gleam, or an external prick or pressure, or some internal uneasiness that stimulates the nerves to unlock the muscular force, or is it free will? Whatever the true answer to the question may be, *your* safety consists in affirming boldly that free will must be the cause of the nervous action. But this, your only line of retreat, you have deliberately closed by saying that, whether the will is free or not, 'the physical results are the same.' By thus dispensing with free will you cause human actions to take their place in the chain of physical sequence, and human combinations of material laws no more justify your conclusions regarding prayer to a free Deity than does the combination of the molecules of water to form frost-flowers upon your window-pane.

Finally, I object to any philosophy, or theology, which selects a special series of natural phenomena as the subject of national supplication, and shrinks from the same act with reference to other phenomena. In reply to my question whether the suppliant voice of a whole nation would have altered the laws of hydraulic pressure in the case of the Bradfield reservoir, you reply, 'Undoubtedly not.' Why not? I would earnestly ask. You advocate prayers for fair weather and for rain. Now the absence or presence of rain depends upon laws of gaseous pressure which are just as immutable as those of water pressure; and the only reason that I can see for the assumption that the one is the object of Divine interference, and the other not, is that one of them is 770 times heavier than the other. Your position puts one in mind of the remark of Galileo, that Nature abhorred a vacuum only to a height of thirty-two feet. 'Divine intervention is thinkable,' you virtually say, 'but only in the case of bodies of small specific gravity.' 'Stupendous interferences,' or 'results of gigantic magnitude,' are not to be expected, but small shiftings reasonably may. Again I ask you, in all earnestness, How came you to know this? To me it appears that you are unwittingly taking dangerous liberties with the established laws of the universe. These laws abolish your distinctions of large and small, and make it as great a miracle to suspend the gravity of a straw as to extinguish the force which holds the solar system together.

With these remarks, and with thanks to you for the opportunity of making them, I would willingly refer the final adjudication of the case between us to the coming time.—Your obedient servant,

JOHN TYNDALL.

Immediately afterwards the editor thus closed the discussion:—

The very number and variety of the letters we have received on the subject of prayer incline us to favour the suggestion of our able correspondent 'M. J. H.,' and end, or suspend, the controversy. We confess to a lurking feeling of regret at doing so, for nothing more important than the efficacy of prayer can occupy the minds of men, and much is to be hoped from any controversy in which intellects so clear, so consistent, so courageous as Professor Tyndall's have part. But in all the many able letters before us we find nothing that really brings us nearer to a solution of our difficulties. In some, our own suggestion is supported—in others Professor Tyndall's broad and bold argument is backed; but nothing *new* is added to either. We leave them, then, to bear what fruit they may, without adding to the discussion what would only lead to a mere multiplication of words. Enough has been said, at present, for candid and thoughtful men. Nobody can mistake Professor Tyndall's line of argument—he himself probably could not make it clearer; while, as for ourselves, we do not presume to dogmatise upon such questions, but we still believe all that we stated, and for the considerations we stated, in the beginning of the discussion—namely, that to pray for the abatement of pestilence is not philosophically absurd.

These are the simple historic antecedents of the following series of articles.

II.

MIRACLES AND SPECIAL PROVIDENCES.[1]

1867.

IT is my privilege to enjoy the friendship of a select number of religious men, with whom I converse frankly upon theological subjects, expressing without disguise the notions and opinions I entertain regarding their tenets, and hearing in return these notions and opinions subjected to criticism. I have thus far found them liberal and loving men, patient in hearing, tolerant in reply, who know how to reconcile the duties of courtesy with the earnestness of debate. From one of these, nearly a year ago, I received a note, recommending strongly to my attention the volume of 'Bampton Lectures' for 1865, in which the question of miracles is treated by Mr. Mozley. Previous to receiving this note, I had in part made the acquaintance of the work through an able and elaborate review of it in the 'Times.' The combined effect of the letter and the review was to make the book the companion of my summer tour in the Alps. There, during the wet and snowy days which were only too prevalent in 1866, and during the days of rest interpolated between days of toil, I made myself more thoroughly conversant with Mr. Mozley's volume. I found it clear and strong—an intellectual tonic, as bracing and pleasant to my mind as the keen air of the mountains was to my body. From time to time I jotted down thoughts regarding it, intending afterwards, if time permitted, to work them up into a coherent whole. Other duties, however, interfered with the complete carrying out of this intention, and what I wrote last summer I now publish, not hoping to be able, within any reasonable time, to render my defence of scientific method more complete.

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[1] 'Fortnightly Review,' New Series, vol. i. p. 645.

Mr. Mozley refers at the outset of his task to the movement against miracles which of late years has taken place, and which determined his choice of a subject. He acquits modern science of having had any great share in the production of this movement. The objection against miracles, he says, does not arise from any minute knowledge of the laws of nature, but simply because they are opposed to that plain and obvious order of nature which everybody sees. The present movement is, he thinks, to be ascribed to the greater earnestness and penetration of the present age. Formerly miracles were accepted without question, because without reflection; but the exercise of what Mr. Mozley calls the historic imagination is a characteristic of our own time. Men are now accustomed to place before themselves vivid images of historic facts; and when a miracle rises to view, they halt before the astounding occurrence, and, realising it with the same clearness as if it were now passing before their eyes, they ask themselves, 'Can this have taken place?' In some instances the effort to answer this question has led to a disbelief in miracles, in others to a strengthening of belief. The end and aim of Mr. Mozley's lectures is to show that the strengthening of belief is the logical result which ought to follow from the examination of the facts.

Attempts have been made by religious men to bring the Scripture miracles within the scope of the order of nature, but all such attempts are rejected by Mr. Mozley as utterly futile and wide of the mark. Regarding miracles as a necessary accompaniment of a revelation, their evidential value in his eyes depends entirely upon their deviation from the order of nature. Thus deviating, they suggest and illustrate a power higher than nature, a 'personal will;' and they commend the person in whom this power is vested as a messenger from on high. Without these credentials such a messenger would have no right to demand belief, even were his assertions regarding his Divine mission backed by a holy life. Nor is it by miracles alone that the order of nature is, or may be, disturbed. The material universe is also the arena of 'special providences.' Under these two heads Mr. Mozley distributes the total preternatural. One form of the preternatural may shade into the other, as one colour passes into another in the rainbow; but, while the line which divides the specially providential from the miraculous cannot be sharply drawn, their distinction broadly expressed is this: that, while a special providence can only excite surmise more or less probable, it is 'the nature of a miracle to give proof, as distinguished from mere surmise, of Divine design.'

Mr. Mozley adduces various illustrations of what he regards to be special providences, as distinguished from miracles. 'The death of Arius,' he says, 'was not miraculous, because the coincidence of the death of a heresiarch taking place when it was peculiarly advantageous to the orthodox faith . . . . was not such as to compel the inference of extraordinary Divine agency; but it was a special providence, because it carried a reasonable appearance of it. The miracle of the Thundering Legion was a special providence, but not a miracle, for the same reason, because the coincidence of an instantaneous fall of rain, in answer to prayer, carried some appearance, but not proof, of preternatural agency.' The eminent lecturer's remarks on this head brought to my recollection certain narratives published in Methodist magazines, which I used to read with avidity when a boy. The title of these exciting stories, if I remember right, was 'The Providence of God asserted,' and in them the most extraordinary escapes from peril were recounted and ascribed to prayer, while equally wonderful instances of calamity were adduced as illustrations of Divine retribution. In such magazines, or elsewhere, I found recorded the case of the celebrated Samuel Hick, which, as it illustrates a whole class of special providences approaching in conclusiveness to miracles, is worthy of mention here. It is related of this holy man—and I, for one, have no doubt of his holiness—that flour was lacking to make the sacramental bread. Grain was present, and a windmill was present, but there was no wind to grind the corn. With faith undoubting, Samuel Hick prayed to the Lord of the winds: the sails turned, the corn was ground, after which the wind ceased. According to the canon of the Bampton Lecturer, this, though carrying a strong appearance of an immediate exertion of Divine energy, lacks by a hair's-breadth the quality of a miracle. For the wind *might* have arisen, and *might* have ceased, in the ordinary course of nature. Hence the occurrence did not 'compel the inference of extraordinary Divine agency.' In like manner Mr. Mozley considers that 'the appearance of the cross to Constantine was a miracle, or a special providence, according to which account of it we adopt. As only a meteoric appearance in the shape of a cross it gave some token of preternatural agency, but not full evidence.'

In the Catholic canton of Switzerland where I now write, and still more among the pious Tyrolese, the mountains are dotted with shrines, containing offerings of all kinds, in acknowledgment of special mercies—legs, feet, arms, and hands—of gold, silver, brass, and wood, according as worldly possessions enabled the grateful heart to express its indebtedness. Most of these offerings are made to the Virgin Mary. They are recognitions of 'special providences,' wrought through the instrumentality of the Mother of God. Mr. Mozley's belief, that of the Methodist chronicler, and that of the Tyrolese peasant, are substantially the same. Each of them assumes that nature, instead of flowing ever onward in the uninterrupted rhythm of cause and effect, is mediately ruled by the free human will. As regards *direct* action upon natural phenomena, man's will is confessedly powerless; but it is the trigger which, by its own free action, liberates the Divine power. In this sense, and to this extent, man, of course, commands nature.

Did the existence of this belief depend solely upon the material benefits derived from it, it could not, in my opinion, last a decade. As a purely objective fact, we should soon see that the distribution of natural phenomena is unaffected by the merits or the demerits of men; that the law of gravitation crushes the simple worshippers of Ottery St. Mary, while singing their hymns, just as surely as if they were engaged in a midnight brawl. The hold of this belief upon the human mind is not due to outward verification, but to the inner warmth, force, and elevation with which it is commonly associated. It is plain, however, that these feelings may exist under the most various forms. They are not limited to Church of England Protestantism—they are not even limited to Christianity. Though less refined, they are certainly not less strong in the heart of the Methodist and the Tyrolese peasant than in the heart of Mr. Mozley. Indeed, those feelings belong to the primal powers of man's nature. A 'sceptic' may have them. They find vent in the battle-cry of the Moslem. They take hue and form in the hunting-grounds of the red Indian; and raise all of them, as they raise the Christian, upon a wave of victory, above the terrors of the grave.

The character, then, of a miracle, as distinguished from a special providence, is that the former furnishes *proof*, while in the case of the latter we have only surmise. Dissolve the element of doubt, and the alleged fact passes from the one class of the preternatural into the other. In other words, if a special providence could be proved to be a special providence, it would cease to be a special providence and become a miracle. There is not the least cloudiness about Mr. Mozley's meaning here. A special providence is a doubtful miracle. Why, then, not call it so? The term employed by Mr. Mozley conveys no negative suggestion, whereas the negation of certainty is the peculiar characteristic of the thing intended to be expressed. There is an apparent unwillingness on the part of the lecturer to call a special providence what his own definition makes it to be. Instead of speaking of it as a doubtful miracle, he calls it 'an invisible miracle.' He speaks of the point of contact of supernatural power with the chain of causation being so high up as to be wholly, or in part, out of sight, whereas the essence of a special providence is the uncertainty whether there is any contact at all, either high or low. By the use of an incorrect term, however, a grave danger is avoided. For the idea of doubt, if kept systematically before the mind, would soon be fatal to the special providence, considered as a means of edification. The term employed, on the contrary, invites and encourages the trust which is necessary to supplement the evidence.

This inner trust, though at first rejected by Mr. Mozley in favour of external proof, is subsequently called upon to do momentous duty in regard to miracles. Whenever the evidence of the miraculous seems incommensurate with the fact which it has to establish, or rather when the fact is so amazing that hardly any evidence is sufficient to establish it, Mr. Mozley invokes 'the affections.' They must urge the reason to accept the conclusion. from which unaided it recoils. The affections and emotions are eminently the court of appeal in matters of real religion, which is an affair of the heart; but they are not, I submit, the court in which to weigh allegations regarding the credibility of physical facts. These must be judged by the dry light of the intellect alone, appeals to the affections being reserved for cases where moral elevation, and not historic conviction, is the aim. It is, moreover, because the result, in the case under consideration, is deemed desirable that the affections are called upon to back it. If undesirable, they would, with equal right, be called upon to act the other way. Even to the disciplined scientific mind this would be a dangerous doctrine. A favourite theory—the desire to establish or avoid a certain result—can so warp the mind as to destroy its powers of estimating facts. I have known men to work for years under a fascination of this kind, unable to extricate themselves from its fatal influence. They had certain data, but not, as it happened, enough. By a process exactly analogous to that invoked by Mr. Mozley they supplemented the data, and went wrong. From that hour their intellects were so blinded to the perception of adverse phenomena that they never reached truth. If, then, to the disciplined scientific mind, this incongruous mixture of proof and trust be fraught with danger, what must it be to the indiscriminate audience which Mr. Mozley addresses? In calling upon this agency he acts the part of Frankenstein. It is a monster thus evoked that we see stalking abroad, in the degrading spiritualistic phenomena of the present day. Again, I say, where the aim is to elevate the mind, to quicken the moral sense, to kindle the fire of religion in the soul, let the affections by all means be invoked; but they must not be permitted to colour our reports, or to influence our acceptance of reports of occurrences in external nature. Testimony as to natural facts is worthless when wrapped in this atmosphere of the affections; the most earnest subjective truth being thus rendered perfectly compatible with the most astounding objective error.

There are questions in judging of which the affections or sympathies are often our best guides, the estimation of moral goodness being one of these. But at this precise point, where they are really of use, Mr. Mozley excludes the affections and demands a miracle as a certificate of character. He will not accept any other evidence of the perfect goodness of Christ. 'No outward life or conduct,' he says, 'however irreproachable, could prove His perfect sinlessness, because goodness depends upon the inward motive, and the perfection of the inward motive is not proved by the outward act.' But surely the miracle is an outward act, and to pass from it to the inner motive imposes a greater strain upon logic than that involved in our ordinary methods of estimating men. There is, at least, moral congruity between the outward goodness and the inner life, but there is no such congruity between the miracle and the life within. The test of moral goodness laid down by Mr. Mozley is not the test of John, who says, 'He that doeth righteousness is righteous;' nor is it the test of Jesus: 'By their fruits ye shall know them; do men gather grapes of thorns, or figs of thistles?' But it *is* the test of another: 'If thou be the Son of God, command that these stones be made bread.' For my own part, I prefer the attitude of Fichte to that of Mr. Mozley. 'The Jesus of John,' says this noble and mighty thinker, 'knows no other God than the True God, in whom we all are, and live, and may be blessed, and out of whom there is only Death and Nothingness. And,' continues Fichte, 'he appeals, and rightly appeals, in support of this truth, not to reasoning, but to the inward practical sense of truth in man, not even knowing any other proof than this inward testimony, "If any man will do the will of Him who sent Me, he shall know of the doctrine whether it be of God."'

Accepting Mr. Mozley's test, with which alone I am now dealing, it is evident that, in the demonstration of moral goodness, the *quantity* of the miraculous comes into play. Had Christ, for example, limited Himself to the conversion of water into wine, He would have fallen short of the performance of Jannes and Jambres; for it is a smaller thing to convert one liquid into another than to convert a dead rod into a living serpent. But Jannes and Jambres, we are informed, were not good. Hence, if Mr. Mozley's test be a true one, a point must exist, on the one side of which miraculous power demonstrates goodness, while on the other side it does not. How is this 'point of contrary flexure' to be determined? It must lie somewhere between the magicians and Moses, for within this space the power passed from the diabolical to the Divine. But how to mark the point of passage—how, out of a purely *quantitative* difference in the visible manifestation of power, we are to infer a total inversion of quality—it is extremely difficult to see. Moses, we are informed, produced a large reptile; Jannes and Jambres produced a small one. I do not possess the intellectual faculty which would enable me to infer, from those data, either the goodness of the one or the badness of the other; and in the highest recorded manifestations of the miraculous I am equally at a loss. Let us not play fast and loose with the miraculous; either it is a demonstration of goodness in all cases or in none. If Mr. Mozley accepts Christ's goodness as transcendent, because He did such works as no other man did, he ought, logically speaking, to accept the works of those who, in His name, had cast out devils, as demonstrating a proportionate goodness on their part. But it is people of this class who are consigned to everlasting fire prepared for the devil and his angels. Such zeal as that of Mr. Mozley for miracles tends, I fear, to eat his religion up. The logical threatens to stifle the spiritual. The truly religious soul needs no miraculous proof of the goodness of Christ. The words addressed to Matthew at the receipt of custom required no miracle to produce obedience. It was by no stroke of the supernatural that Jesus caused those sent to seize Him to go backward and fall to the ground. It was the sublime and holy effluence from within, which needed no prodigy to commend it to the reverence even of his foes.

As regards the function of miracles in the founding of a religion, Mr. Mozley institutes a comparison between the religion of Christ and that of Mahomet; and he derides the latter as 'irrational' because it does not profess to adduce miracles in proof of its supernatural origin. But the religion of Mahomet, notwithstanding this drawback, has thriven in the world, and at one time it held sway over larger populations than Christianity itself. The spread and influence of Christianity are, however, brought forward by Mr. Mozley as 'a permanent, enormous, and incalculable practical result' of Christian miracles; and he makes use of this result to strengthen his plea for the miraculous. His logical warrant for this proceeding is not clear. It is the method of science, when a phenomenon presents itself, towards the production of which several elements may contribute, to exclude them one by one, so as to arrive at length at the truly effective cause. Heat, for example, is associated with a phenomenon; we exclude heat, but the phenomenon remains: hence, heat is not its cause. Magnetism is associated with a phenomenon; we exclude magnetism, but the phenomenon remains: hence, magnetism is not its cause. Thus, also, when we seek the cause of the diffusion of a religion—whether it be due to miracles, or to the spiritual force of its founders—we exclude the miracles, and, finding the result unchanged, we infer that miracles are not the effective cause. This important experiment Mahometanism has made for us. It has lived and spread without miracles; and to assert, in the face of this, that Christianity has spread *because* of miracles, is not more opposed to the spirit of science than to the common sense of mankind.

The incongruity of inferring moral goodness from miraculous power has been dwelt upon above; in another particular also the strain put by Mr. Mozley upon miracles is, I think, more than they can bear. In consistency with his principles, it is difficult to see how he is to draw from the miracles of Christ any certain conclusion as to His Divine nature. He dwells very forcibly on what he calls 'the argument from experience,' in the demolition of which he takes evident delight. He destroys the argument, and repeats it, for the mere pleasure of again and again knocking the breath out of it. Experience, he urges, can only deal with the past; and the moment we attempt to project experience a hair's-breadth beyond the point it has at any moment reached, we are condemned by reason. It appears to me that when he infers from Christ's miracles a Divine and altogether superhuman energy, Mr. Mozley places himself precisely under this condemnation. For what is his logical ground for concluding that the miracles of the New Testament illustrate Divine power? May they not be the result of expanded human power? A miracle he defines as something impossible to man. But how does he know that the miracles of the New Testament are impossible to man? Seek as he may, he has absolutely no reason to adduce save this —that man has never hitherto accomplished such things. But does the fact that man *has* never raised the dead prove that he *can* never raise the dead? 'Assuredly not,' must be Mr. Mozley's reply; 'for this would be pushing experience beyond the limit it has now reached— which I pronounce unlawful.' Then a period may come when man will be able to raise the dead. If this be conceded—and I do not see how Mr. Mozley can avoid the concession—it destroys the necessity of inferring Christ's Divinity from His miracles. He, it may be contended, antedated the humanity of the future; as a mighty tidal wave leaves high upon the beach a mark which by-and-by becomes the general level of the ocean. Turn the matter as you will, no other warrant will be found for the all-important conclusion that Christ's miracles demonstrate Divine power, than an argument which has been stigmatised by Mr. Mozley as a 'rope of sand'—the argument from experience.

The learned Bampton Lecturer would be in this position, even had he seen with his own eyes every miracle recorded in the New Testament. But he has *not* seen these miracles; and his intellectual plight is therefore worse. He accepts these miracles on testimony. Why does he believe that testimony? How does he know that it is not delusion; how is he sure that it is not even fraud? He will answer, that the writing bears the marks of sobriety and truth; and that in many cases the bearers of this message to mankind sealed it with their blood. Granted with all my heart; but whence the value of all this? Is it not solely derived from the fact that men, *as we know them*, do not sacrifice their lives in the attestation of that which they know to be untrue? Does not the entire value of the testimony of the apostles depend ultimately upon our experience of human nature? It appears, therefore, that those said to have seen the miracles, based their inferences from what they saw on the argument from experience; and that Mr. Mozley bases his belief in their testimony on the same argument. The weakness of his conclusion is quadrupled by this double insertion of a principle of belief, to which he flatly denies rationality. His reasoning, in fact, cuts two ways—if it destroys our trust in the order of nature, it far more effectually abolishes the basis on which Mr. Mozley seeks to found the Christian religion.

Over this argument from experience, which at bottom is *his* argument, Mr. Mozley rides rough-shod. There is a dash of scorn in the energy with which he tramples on it. Probably some previous writer had made too much of it, and thus invited his powerful assault. Finding the difficulty of belief in miracles to rise from their being in contradiction to the order of nature, he sets himself to examine the grounds of our belief in that order. With a vigour of logic rarely equalled, and with a confidence in its conclusions never surpassed, he disposes of this belief in a manner calculated to startle those who, without due examination, had come to the conclusion that the order of nature was secure.

What we mean, he says, by our belief in the order of nature, is the belief that the future will be like the past. There is not, according to Mr. Mozley, the slightest rational basis for this belief.

> 'That any cause in nature is more permanent than its existing and known effects, extending further, and about to produce other and more instances besides what it has produced already, we have no evidence. Let us imagine,' he continues, 'the occurrence of a particular physical phenomenon for the first time. Upon that single occurrence we should have but the very faintest expectation of another. If it did occur again, once or twice, so far from

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of a man who feels his position to be a strong one, 'has philosophy loosened the connection of the order of nature with the ground of reason, befriending in exact proportion as it has done this the principle of miracles.' For 'this belief not having itself a foundation in reason, the ground is gone upon which it could be maintained that miracles, as opposed to the order of nature, are opposed to reason.' When we regard this belief in connection with science, 'in which connection it receives a more imposing name, and is called the inductive principle,' the result is the same. 'The inductive principle is only this unreasoning impulse applied to a scientifically ascertained fact. . . . . Science has led up to the fact; but there it stops, and for converting this fact into a law, a totally unscientific principle comes into play, the same as that which generalises the commonest observation of nature.'

The eloquent pleader of the cause of miracles passes over without a word the *results* of scientific investigation, as proving anything rational regarding the principles or method by which such results have been achieved. Here, as elsewhere, he declines the test, 'By their fruits shall ye know them.' Perhaps our best way of proceeding will be to give one or two examples of the mode in which men of science apply the unintelligent impulse with which Mr. Mozley credits them, and which shall show, by illustration, the surreptitious method whereby they climb from the region of facts to that of laws.

Before the sixteenth century it was known that water rises in a pump; the effect being then explained by the maxim that 'Nature abhors a vacuum.' It was not known that there was any limit to the height to which the water would ascend, until, on one occasion, the gardeners of Florence, while attempting to raise water to a very great elevation, found that the column ceased at a height of thirty-two feet. Beyond this all the skill of the pump-maker could not get it to rise. The fact was brought to the notice of Galileo, and he, soured by a world which had not treated his science over kindly, is said to have twitted the philosophy of the time by remarking that nature evidently abhorred a vacuum only to a height of thirty-two feet. Galileo, however, did not solve the problem. It was taken up by his pupil Torricelli, who pondered it, and, in doing so, various thoughts regarding it arose in his mind. It occurred to him that the water might be forced into the tube by a pressure applied to the surface of the water outside. But where, under the actual circumstances, was such a pressure to be found? After much reflection, it flashed upon Torricelli that the atmosphere might possibly exert this pressure; that the impalpable air might possess weight, and that a column of water thirty-two feet high might be of the exact weight necessary to hold the pressure of the atmosphere in equilibrium.

There is much in this process of pondering and its results, which it is impossible to analyse. It is by a kind of inspiration that we rise from the wise and sedulous contemplation of facts, to the principles on which they depend. The mind is, as it were, a photographic plate, which is gradually cleansed by the effort to think rightly, and which, when so cleansed, and not before, receives impressions from the light of truth. This passage from facts to principles is called induction; and induction, in its highest form, is, as just stated, a kind of inspiration. But, to make it sure, the inward sight must be shown to be in accordance with outward fact. To prove or disprove the induction, we must resort to deduction and experiment.

Torricelli reasoned thus: If a column of water thirty-two feet high holds the pressure of the atmosphere in equilibrium, a shorter column of a heavier liquid ought to do the same. Now, mercury is thirteen times heavier than water; hence, if my induction be correct, the atmosphere ought to be able to sustain only thirty inches of mercury. Here, then, is a deduction which can be immediately submitted to experiment. Torricelli took a glass tube a yard or so in length, closed at one end and open at the other, and filling it with mercury, he stopped the open end with his thumb, and inverted it in a basin filled with the liquid metal. One can imagine the feeling with which Torricelli removed his thumb, and the delight he experienced when he found that his thought had forestalled a fact never before revealed to human eyes. The column sank, but it ceased to sink at a height of thirty inches, leaving the Torricellian vacuum overhead. From that hour the theory of the pump was established.

The celebrated Pascal followed Torricelli with another deduction. He reasoned thus: If the mercurial column be supported by the atmosphere, the higher we ascend in the air, the lower the column ought to sink, for the less will be the weight of the air overhead. He caused a friend to ascend the Puy de Dôme, carrying with him a barometric column; and it was found that during the ascent the column sank, and that during the subsequent descent the column rose.

Between the time here referred to and the present, millions of experiments have been made upon this subject. Every village pump is an apparatus for such experiments. In thousands of instances, moreover, pumps have refused to work; but on examination it has infallibly been found that the well was dry, that the pump required priming, or that some other defect in the apparatus accounted for the anomalous action. In every case of the kind the skill of the pump-maker has been found to be the true remedy. In no case has the pressure of the atmosphere ceased; constancy, as regards the lifting of pump-water, has been hitherto the demonstrated rule of nature. So also as regards Pascal's experiment. His experience has been the universal experience ever since. Men have climbed mountains, and gone up in balloons; but no deviation from Pascal's result has ever been observed. Barometers, like pumps, have refused to act; but instead of indicating any suspension of the operations of nature, or any interference on the part of its Author with atmospheric pressure, examination has in every instance fixed the anomaly upon the instruments themselves. It is this welding, then, of rigid logic to verifying fact that Mr. Mozley refers to an 'unreasoning impulse.'

Let us now briefly consider the case of Newton. Before his time men had occupied themselves with the problem of the solar system. Kepler had deduced, from a vast mass of observations, those general expressions of planetary motion known as 'Kepler's laws.' It had been observed that a magnet attracts iron; and by one of those flashes of inspiration which reveal to the human mind the vast in the minute, the general in the particular, it had been inferred, that the force by which bodies fall to the earth might also be an attraction. Newton pondered all these things. He had a great power of pondering. He could look into the darkest subject until it became entirely luminous. How this light arises we cannot explain; but, as a matter of fact, it does arise. Let me remark here, that this power of pondering facts is one with which the ancients could have been but imperfectly acquainted. They, for the most part, found the exercise of fantasy more pleasant than the brooding over facts. Hence it is, that when those whose education has been derived from the ancients speak of 'the reason of man,' they are apt to omit from their conception of reason one of its greatest powers. Well, Newton slowly marshalled his thoughts, or rather they came to him while he 'intended his mind,' rising like a series of intellectual births out of chaos. He made this idea of attraction his own. But, to apply the idea to the solar system, it was necessary to know the magnitude of the attraction, and the law of its variation with the distance. His conceptions first of all passed from the action of the earth as a whole, to that of its constituent particles. And persistent thought brought more and more clearly out the final divination, that every particle of matter attracts every other particle with a force varying inversely as the square of the distance between the particles.

This is Newton's celebrated law of inverse squares. Here we have the flower and outcome of his induction; and how to verify it, or to disprove it, was the next question. The first step of Newton in this direction was to prove, mathematically, that if this law of attraction be the true one; if the earth be constituted of particles which obey this law; then the action of a sphere equal to the earth in size on a body outside of it, is the same as that which would be exerted if the whole mass of the sphere were contracted to a point at its centre. Practically speaking, then, the centre of the earth is the point from which distances must be measured to bodies attracted by the earth.

From experiments executed before his time, Newton knew the amount of the earth's attraction at the earth's surface, or at a distance of 4,000 miles from its centre. His object now was to measure the attraction at a greater distance, and thus to determine the law of its diminution. But how was he to find a body at a sufficient distance? He had no balloon; and even if he had, he knew that any height to which he could attain would be too small to enable him to solve his problem. What did he do? He fixed his thoughts upon the moon;—a body 240,000 miles, or sixty times the earth's radius, from the earth's centre. He virtually weighed the moon, and found that weight to be $\frac{1}{3600}$th of what it would be at the earth's surface. This is exactly what his theory required. I will not dwell here upon the pause of Newton after his first calculations, or speak of his self-denial in withholding them, because they did not quite agree with the observations then at his command. Newton's action in this matter is the normal action of the scientific mind. If it were otherwise—if scientific men were not accustomed to demand verification—if they were satisfied with the imperfect while the perfect is attainable, their science, instead of being, as it is, a fortress of adamant, would be a house of clay, ill-fitted to bear the buffetings of the theologic storms to which it is periodically exposed.

Thus we see that Newton, like Torricelli, first pondered his facts, illuminated them with persistent thought, and finally divined the character of the force of gravitation. But, having thus travelled inward to the principle, he reversed his steps, carried the principle outwards, and justified it by demonstrating its fitness to external nature.

And here, in passing, I would notice a point which is well worthy of attention. Kepler had deduced his laws from observation. As far back as those observations extended, the planetary motions had obeyed these laws; and neither Kepler nor Newton entertained a doubt as to their continuing to obey them. Year after year, as the ages rolled, they believed that those laws would continue to illustrate themselves in the heavens. But this was not sufficient. The scientific mind can find no repose in the mere registration of sequence in nature. The further question intrudes itself with resistless might, Whence comes the sequence? What is it that binds the consequent to its antecedent in nature? The truly scientific intellect never can attain rest until it reaches the *forces* by which the observed succession is produced. It was thus with Torricelli; it was thus with Newton; it is thus pre-eminently with the scientific man of to-day. In common with the most ignorant, he shares the belief that spring will succeed winter, that summer will succeed spring, that autumn will succeed summer, and that winter will succeed autumn. But he knows still further—and this knowledge is essential to his intellectual repose—that this succession, besides being permanent, is, under the circumstances, *necessary*; that the gravitating force exerted between the sun, and a revolving sphere with an axis inclined to the plane of its orbit, must produce the observed succession of the seasons. Not until this relation between forces and phenomena has been established, is the law of reason rendered concentric with the law of nature; and not until this is effected does the mind of the scientific philosopher rest in peace.

The expectation of likeness, then, in the procession of phenomena, is not that on which the scientific mind founds its belief in the order of nature. If the force be *permanent* the phenomena are *necessary*, whether they resemble or do not resemble anything that has gone before. Hence, in judging of the order of nature, our enquiries eventually relate to the permanence of force. From Galileo to Newton, from Newton to our own time, eager eyes have been scanning the heavens, and clear heads have been pondering the phenomena of the solar system. The same eyes and minds have been also observing, experimenting, and reflecting on the action of gravity at the surface of the earth. Nothing has occurred to indicate that the operation of the law has for a moment been suspended; nothing has ever intimated that nature has been crossed by spontaneous action, or that a state of things at any time existed which could not be rigorously deduced from the preceding state.

Given the distribution of matter, and the forces in operation, in the time of Galileo, the competent mathematician of that day could predict what is now occurring in our own. We calculate eclipses in advance, and find our calculations true to the second. We determine the dates of those that have occurred in the early times of history, and find calculation and history at peace. Anomalies and perturbations in the planets have been over and over again observed; but these, instead of demonstrating any inconstancy on the part of natural law, have invariably been reduced to consequences of that law. Instead of referring the perturbations of Uranus to any interference on the part of the Author of nature with the law of gravitation, the question which the astronomer proposed to himself was, 'How, in accordance with this law, can the perturbation be produced?' Guided by a principle, he was enabled to fix the point of space in which, if a mass of matter were placed, the observed perturbations would follow. We know the result. The practical astronomer turned his telescope towards the region which the intellect of the theoretic astronomer had already explored, and the planet now named Neptune was found in its predicted place. A very respectable outcome, it will be admitted, of an impulse which 'rests upon no rational grounds, and can be traced to no rational principle;' which possesses 'no intellectual character;' which 'philosophy' has uprooted from 'the ground of reason,' and fixed in that 'large irrational department' discovered for it, by Mr. Mozley, in the hitherto unexplored wilderness of the human mind.

The proper function of the inductive principle, or the belief in the order of nature, says Mr. Mozley, is 'to act as a practical basis for the affairs of life, and the carrying on of human society.' But what, it may be asked, has the planet Neptune, or the belts of Jupiter, or the whiteness about the poles of Mars, to do with the affairs of society? How is society affected by the fact that the sun's atmosphere contains sodium, or that the nebula of Orion contains hydrogen gas? Nineteen-twentieths of the force employed in the exercise of the inductive principle, which, reiterates Mr. Mozley, is 'purely practical,' have been expended upon subjects as unpractical as these. What practical interest has society in the fact that the spots on the sun have a decennial period, and that when a magnet is closely watched for half a century, it is found to perform small motions which synchronise with the appearance and disappearance of the solar spots? And yet, I doubt not, Sir Edward Sabine would deem a life of intellectual toil amply rewarded by being privileged to solve, at its close, these infinitesimal motions.

The inductive principle is founded in man's desire to know—a desire arising from his position among phenomena which are reducible to order by his intellect. The material universe is the complement of the intellect; and, without the study of its laws, reason could never have awakened to the higher forms of self-consciousness at all. It is the non-ego, through and by which the ego is endowed with self-discernment. We hold it to be an exercise of reason to explore the meaning of a universe to which we stand in this relation, and the work we have accomplished is the proper commentary on the methods we have pursued. Before these methods were adopted the unbridled imagination roamed through nature, putting in the place of law the figments of superstitious dread. For thousands of years witchcraft, and magic, and miracles, and special providences, and Mr. Mozley's 'distinctive reason of man,' had the world to themselves. They made worse than nothing of it—*worse*, I say, because they let and hindered those who might have made something of it. Hence it is, that during a single lifetime of this era of 'unintelligent impulse,' the progress in knowledge is all but infinite as compared with that of the ages which preceded ours.

The believers in magic and miracles of a couple of centuries ago had all the strength of Mr. Mozley's present logic on their side. They had done for themselves what he rejoices in having so effectually done for us—cleared the ground of the belief in the order of nature, and declared magic, miracles, and witchcraft to be matters for 'ordinary evidence' to decide. 'The principle of miracles' thus 'befriended' had free scope, and we know the result. Lacking that rock-barrier of natural knowledge which we, laymen of England, now possess, keen jurists and cultivated men were hurried on to deeds, the bare recital of which makes the blood run cold. Skilled in all the rules of human evidence, and versed in all the arts of cross-examination, these men, nevertheless, went systematically astray, and committed the deadliest wrongs against humanity. And why? Because they could not put Nature into the witness-box, and question her; of her voiceless 'testimony' they knew nothing. In all cases between man and man, their judgment was to be relied on; but in all cases between man and nature, they were blind leaders of the blind.[1]

Mr. Mozley concedes that it would be no great result if miracles were only accepted by the ignorant and superstitious, 'because it is easy to satisfy those who do not enquire.' But he does consider it 'a great result' that they have been accepted by the educated. In what sense educated? Like those statesmen, jurists, and church dignitaries whose education was unable to save them from the frightful errors glanced at above? Not even in this sense; for the great mass of Mr. Mozley's educated people had no legal training, and must have been absolutely defenceless against delusions which could set even that training at naught. Like nine-tenths of our clergy at the present day, they were versed in the literature of Greece, Rome, and Judea; but as regards a knowledge of nature, which is here the one thing needful, they were 'noble savages,' and nothing more. In the case of miracles, then, it behoves us to understand the weight of the negative, before we assign a value to the positive; to comprehend the depositions of nature before we attempt to measure, with them, the evidence of men. We have only to open our eyes to see what honest and even intellectual men and women are capable of, as to judging evidence, in this nineteenth century of the Christian era, and in latitude fifty-two degrees north. The experience thus gained ought, I imagine, to influence our opinion regarding the testimony of people inhabiting a sunnier clime, with a richer imagination, and without a particle of that restraint which the discoveries of physical science have imposed upon mankind.

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[1] 'In 1664 two women were hung in Suffolk, under a sentence of Sir Matthew Hale, who took the opportunity of declaring that the reality of witchcraft was unquestionable; "for first, the Scriptures had affirmed so much; and secondly, the wisdom of all nations had provided laws against such persons, which is an argument of their confidence of such a crime." Sir Thomas Browne, who was a great physician as well as a great writer, was called as a witness, and swore "that he was clearly of opinion that the persons were bewitched."'—Lecky's *History of Rationalism*, vol. i. p. 120.

Having thus submitted Mr. Mozley's views to the examination which they challenged at the hands of a student of nature, I am unwilling to quit his book without expressing my high admiration and respect for his ability. His failure, as I consider it to be, must, I think, await all attempts, however able, to deal with the material universe by logic and imagination, unaided by experiment and observation. With regard to the style of the book, I willingly subscribe to the description with which the 'Times' winds up its able and appreciative review. 'It is marked throughout with the most serious and earnest conviction, but is without a single word from first to last of asperity or insinuation against opponents, and this not from any deficiency of feeling as to the importance of the issue, but from a deliberate and resolutely maintained self-control, and from an over-ruling, ever-present sense of the duty, on themes like these, of a more than judicial calmness.'

[To the argument regarding the quantity of the miraculous, introduced at page 387, Mr. Mozley has done me the honour of publishing a Reply in the seventh volume of the 'Contemporary Review.'—J. T.]

ADDITIONAL REMARKS ON MIRACLES.

Among the scraps of manuscript, written at the time when Mr. Mozley's work occupied my attention, I find the following reflections:—

With regard to the influence of modern science which Mr. Mozley rates so low, one obvious effect of it is to enhance the magnitude of many of the recorded miracles, and to increase proportionably the difficulties of belief. The ancients knew but little of the vastness of the universe. The Rev. Mr. Kirkman, for example, has shown what inadequate notions the Jews entertained regarding the 'firmament of heaven;' and Professor Airy refers to the case of a Greek philosopher who was persecuted for hazarding the assertion, then deemed monstrous, that the sun might be as large as the whole country of Greece. The concerns of a universe, regarded from this point of view, were much more commensurate with man and his concerns than those of the universe which science now reveals to us; and hence that to suit man's purposes, or that in compliance with his prayers, changes should occur in the order of the universe, was more easy of belief in the ancient world than it can be now. In the very magnitude which it assigns to natural phenomena, science has augmented the distance between them and man, and increased the popular belief in their orderly progression.

As a natural consequence the demand for evidence is more exacting than it used to be, whenever it is affirmed that the order of nature has been disturbed. Let us take as an illustration the miracle by which the victory of Joshua over the Amorites was rendered complete. In this case the sun is reported to have stood still for 'a whole day' upon Gibeon, and the moon in the valley of Ajalon. An Englishman of average education at the present day would naturally demand a greater amount of evidence to prove that this occurrence took place, than would have satisfied an Israelite in the age succeeding that of Joshua. For, to the one, the miracle probably consisted of the stoppage of a fiery ball less than a yard in diameter, while to the other it would be the stoppage of an orb fourteen hundred thousand times the earth in size. And even accepting the interpretation that Joshua dealt with what was apparent merely, but that what really occurred was the suspension of the earth's rotation, I think the right to exercise a greater reserve in accepting the miracle, and to demand stronger evidence in support of it than that which would have satisfied an ancient Israelite, or than that which would now satisfy the archaic editor of the 'Dublin Review,' will still be conceded to a man of science.

There is a scientific as well as a historic imagination; and when, by the exercise of the former, the stoppage of the earth's rotation is clearly realised, the event assumes proportions so vast, in comparison with the result to be obtained by it, that belief reels under the reflection. The energy here involved is equal to that of six trillions of horses working for the whole of the time employed by Joshua in the destruction of his foes. The amount of power thus expended would be sufficient to supply every individual of an army a thousand times the strength of that of Joshua, with a thousand times the fighting power of each of Joshua's soldiers, not for the few hours necessary to the extinction of a handful of Amorites, but for millions of years. All this wonder is silently passed over by the sacred historian, confessedly because he knew nothing about it. Whether, therefore, we consider the miracle as purely evidential, or as a practical means of vengeance, the same lavish squandering of energy stares us in the face. If evidential, the energy was wasted, because the Israelites knew nothing of its amount; if simply destructive, then the ratio of the quantity lost to that employed, may be inferred from the foregoing figures.

To other miracles similar remarks apply. Transferring our thoughts from this little sand-grain of an earth to the immeasurable heavens, where countless worlds with freights of life probably revolve unseen, the very suns which warm them being barely visible across abysmal space; reflecting that beyond these sparks of solar fire, suns innumerable may burn, whose light can never stir the optic nerve at all; and bringing these reflections face to face with the idea of the Builder and Sustainer of it all showing Himself in a burning bush, exhibiting His hinder parts, or behaving in other familiar ways ascribed to Him in the Jewish Scriptures, the incongruity must appear. Did this credulous prattle of the ancients about miracles stand alone; were it not associated with words of imperishable wisdom, and with examples of moral grandeur unmatched elsewhere in the history of the human race, both the miracles and their 'evidences' would have long since ceased to be the transmitted inheritance of intelligent men. Influenced by the thoughts which this universe inspires, well may we exclaim in David's spirit, if not in David's words: 'When I consider the heavens, the work of thy fingers, the moon, and the stars, which thou hast ordained; what is man that thou shouldst be mindful of him, or the son of man that thou shouldst so regard him?'

If you ask me who is to limit the outgoings of Almighty power, my answer is, not I. If you should urge that if the Builder and the Maker of this universe chose to stop the rotation of the earth, or to take the form of a burning bush, there is nothing to prevent Him from doing so, I am not prepared to contradict you. I neither agree with you nor differ from you, for it is a subject of which I know nothing. But I observe that in such questions regarding Almighty power, your enquiries relate, not to that power as it is actually displayed in the universe, but to the power of your own imagination. Your question is, not has the Omnipotent done so and so? or is it in the least degree likely that the Omnipotent should do so and so? but, is my imagination competent to picture a Being able and willing to do so and so? I am not prepared to deny your competence. To the human mind belongs the faculty of enlarging and diminishing, of distorting and combining, indefinitely the objects revealed by the senses. It can imagine a mouse as large as an elephant, an elephant as large as a mountain, and a mountain as high as the stars. It can separate congruities and unite incongruities. We see a fish and we see a woman; we can drop one half of each, and unite in idea the other two halves to a mermaid. We see a horse and we see a man; we are able to drop one half of each, and unite the other two halves to a centaur. Thus also the pictorial representations of the Deity, the bodies and wing of cherubs and seraphs, the hoofs, horns, and tail of the Evil One, the joys of the blessed, and the torments of the damned, have been elaborated from materials furnished to the imagination by the senses. And it behoves you and me to take care that our notions of the Power which rules the universe are not mere fanciful or ignorant enlargements of human power. The capabilities of what you call your reason are not denied. By the exercise of the faculty here adverted to, you can picture to yourself a Being able and willing to do any and every conceivable thing. You are right in saying that in opposition to this Power science is of no avail. Mr. Mozley would call it 'a weapon of air.' The man of science, however, while accepting the figure, would probably reverse its application, thinking it is not science which is here the thing of air, but that unsubstantial pageant of the imagination to which the solidity of science is opposed.

III.

SCIENTIFIC MATERIALISM.

1868.

THE celebrated Fichte, in his lectures on the 'Vocation of the Scholar,' insisted on a culture which should not be one-sided, but all-sided. The scholar's intellect was to expand spherically, and not in a single direction only. In one direction, however, Fichte required that the scholar should apply himself directly to nature, become a creator of knowledge, and thus repay, by original labours of his own, the immense debt he owed to the labours of others. It was these which enabled him to supplement the knowledge derived from his own researches, so as to render his culture rounded and not one-sided.

As regards science, Fichte's idea is to some extent illustrated by the constitution and labours of the British Association. We have here a body of men engaged in the pursuit of Natural Knowledge, but variously engaged. While sympathising with each of its departments, and supplementing his culture by knowledge drawn from all of them, each student amongst us selects one subject for the exercise of his own original faculty—one line, along which he may carry the light of his private intelligence a little way into the darkness by which all knowledge is surrounded. Thus, the geologist deals with the rocks; the biologist with the conditions and phenomena of life; the astronomer with stellar masses and motions; the mathematician with the relations of space and number; the chemist pursues his atoms; while the physical investigator has his own large field in optical, thermal, electrical, acoustical, and other phenomena. The British Association then, as a whole, faces physical nature on all sides, and pushes knowledge centrifugally outwards, the sum of its labours constituting what Fichte might call the *sphere* of natural knowledge. In the meetings of the Association it is found necessary to resolve this sphere into its component parts, which take concrete form under the respective letters of our Sections.

This is the Mathematical and Physical Section. Mathematics and physics have been long accustomed to coalesce. For, no matter how subtle a natural phenomenon may be, whether we observe it in the region of sense, or follow it into that of imagination, it is in the long run reducible to mechanical laws. But the mechanical data once guessed or given, mathematics become all-powerful as an instrument of deduction. The command of Geometry over the relations of space, and the far-reaching power which Analysis confers, are potent both as means of physical discovery, and of reaping the entire fruits of discovery. Indeed, without mathematics, expressed or implied, our knowledge of physical science would be both friable and incomplete.

Side by side with the mathematical method we have the method of experiment. Here, from a starting-point furnished by his own researches or those of others, the investigator proceeds by combining intuition and verification. He ponders the knowledge he possesses, and tries to push it further; he guesses, and checks his guess; he conjectures, and confirms or explodes his conjecture. These guesses and conjectures are by no means leaps in the dark; for knowledge once gained casts a faint light beyond its own immediate boundaries. There is no discovery so limited as not to illuminate something beyond itself. The force of intellectual penetration into this penumbral region which surrounds actual knowledge is not, as some seem to think, dependent upon method, but upon the genius of the investigator. There is, however, no genius so gifted as not to need control and verification. The profoundest minds know best that Nature's ways are not at all times their ways, and that the brightest flashes in the world of thought are incomplete until they have been proved to have their counterparts in the world of fact. Thus the vocation of the true experimentalist may be defined as the continued exercise of spiritual insight, and its incessant correction and realisation. His experiments constitute a body, of which his purified intuitions are, as it were, the soul.

Partly through mathematical and partly through experimental research, physical science has, of late years, assumed a momentous position in the world. Both in a material and in an intellectual point of view it has produced, and it is destined to produce, immense changes —vast social ameliorations, and vast alterations in the popular conception of the origin, rule, and governance of natural things. By science, in the physical world, miracles are wrought, while philosophy is forsaking its ancient metaphysical channels, and pursuing others which have been opened, or indicated, by scientific research. This must become more and more the case as philosophical writers become more deeply imbued with the methods of science, better acquainted with the facts which scientific men have established, and with the great theories which they have elaborated.

If you look at the face of a watch, you see the hour and minute-hands, and possibly also a second-hand, moving over the graduated dial. Why do these hands move? and why are their relative motions such as they are observed to be? These questions cannot be answered without opening the watch, mastering its various parts, and ascertaining their relationship to each other. When this is done, we find that the observed motion of the hands follows of necessity from the inner mechanism of the watch, when acted upon by the force invested in the spring.

The motion of the hands may be called a phenomenon of art, but the case is similar with the phenomena of nature. These also have their inner mechanism, and their store of force to set that mechanism going. The ultimate problem of physical science is to reveal this mechanism, to discern this store, and to show that from the combined action of both, the phenomena of which they constitute the basis must, of necessity, flow.

I thought an attempt to give you even a brief and sketchy illustration of the manner in which scientific thinkers regard this problem, would not be uninteresting to you on the present occasion; more especially as it will give me occasion to say a word or two on the tendencies and limits of modern science; to point out the region which men of science claim as their own, and where it is mere waste of time to oppose their advance; and also to define, if possible, the bourne between this and that other region, to which the questionings and yearnings of the scientific intellect are directed in vain.

But here your tolerance will be needed. It was the American Emerson, I think, who said that it is hardly possible to state any truth strongly, without apparent injustice to some other truth. Truth is often of a dual character, taking the form of a magnet with two poles; and many of the differences which agitate the thinking part of mankind are to be traced to the exclusiveness with which partisan reasoners dwell upon one half of the duality, in forgetfulness of the other. The proper course appears to be to state both halves strongly, and allow each its fair share in the formation of the resultant conviction. But this waiting for the statement of the two sides of a question implies patience. It implies a resolution to suppress indignation, if the statement of the one half should clash with our convictions; and to repress equally undue elation, if the half-statement should happen to chime in with our views. It implies a determination to wait calmly for the statement of the whole, before we pronounce judgment in the form of either acquiescence or dissent.

This premised, and I trust accepted, let us enter upon our task. There have been writers who affirmed that the pyramids of Egypt were natural productions; and in his early youth Alexander von Humboldt wrote a learned essay with the express object of refuting this notion. We now regard the pyramids as the work of men's hands, aided probably by machinery of which no record remains. We picture to ourselves the swarming workers toiling at those vast erections, lifting the inert stones, and, guided by the volition, the skill, and possibly at times by the whip of the architect, placing them in their proper positions. The blocks, in this case, were moved and posited by a power external to themselves, and the final form of the pyramid expressed the thought of its human builder.

Let us pass from this illustration of constructive power to another of a different kind. When a solution of common salt is slowly evaporated, the water which holds the salt in solution disappears, but the salt itself remains behind. At a certain stage of concentration the salt can no longer retain the liquid form; its particles, or molecules, as they are called, begin to deposit themselves as minute solids, so minute, indeed, as to defy all microscopic power. As evaporation continues, solidification goes on, and we finally obtain, through the clustering together of innumerable molecules, a finite crystalline mass of a definite form. What is this form? It sometimes seems a mimicry of the architecture of Egypt. We have little pyramids built by the salt, terrace above terrace from base to apex, forming a series of steps, resembling those up which the Egyptian traveller is dragged by his guides. The human mind is as little disposed to look unquestioning at these pyramidal salt-crystals, as to look at the pyramids of Egypt, without enquiring whence they came. How, then, are those salt-pyramids built up?

Guided by analogy, you may, if you like, suppose that, swarming among the constituent molecules of the salt, there is an invisible population, controlled and coerced by some invisible master, and placing the atomic blocks in their positions. This, however, is not the scientific idea, nor do I think your good sense will accept it as a likely one. The scientific idea is, that the molecules act upon each other without the intervention of slave labour; that they attract each other, and repel each other, at certain definite points, or poles, and in certain definite directions; and that the pyramidal form is the result of this play of attraction and repulsion. While, then, the blocks of Egypt were laid down by a power external to themselves, these molecular blocks of salt are self-posited, being fixed in their places by the forces with which they act upon each other.

I take common salt as an illustration, because it is so familiar to us all; but any other crystalline substance would answer my purpose equally well. Everywhere, in fact, throughout inorganic nature, we have this formative power, as Fichte would call it—this structural energy ready to come into play, and build the ultimate particles of matter into definite shapes. The ice of our winters, and of our polar regions, is its handiwork, and so also are the quartz, felspar, and mica of our rocks. Our chalk-beds are for the most part composed of minute shells, which are also the product of structural energy; but behind the shell, as a whole, lies a more remote and subtle formative act. These shells are built up of little crystals of calc-spar, and, to form these crystals, the structural force had to deal with the intangible molecules of carbonate of lime. This tendency on the part of matter to organise itself, to grow into shape, to assume definite forms in obedience to the definite action of force, is, as I have said, all-pervading. It is in the ground on which you tread, in the water you drink, in the air you breathe. Incipient life, as it were, manifests itself throughout the whole of what we call inorganic nature.

The forms of the minerals resulting from this play of polar forces are various, and exhibit different degrees of complexity. Men of science avail themselves of all possible means of exploring their molecular architecture. For this purpose they employ in turn, as agents of exploration, light, heat, magnetism, electricity, and sound. Polarised light is especially useful and powerful here. A beam of such light, when sent in among the molecules of a crystal, is acted on by them, and from this action we infer with more or less clearness the manner in which the molecules are arranged. That differences, for example, exist between the inner structure of rock-salt and crystallised sugar or sugar-candy, is thus strikingly revealed. These actions often display themselves in chromatic phenomena of great splendour, the play of molecular force being so regulated as to remove some of the coloured constituents of white light, leaving others with increased intensity behind.

And now let us pass from what we are accustomed to regard as a dead mineral, to a living grain of corn. When this is examined by polarised light, chromatic phenomena similar to those noticed in crystals are observed. And why? Because the architecture of the grain resembles the architecture of the crystal. In the grain also the molecules are set in definite positions, and in accordance with their arrangement they act upon the light. But what has built together the molecules of the corn? Regarding crystalline architecture, I have already said that you may, if you please, consider the atoms and molecules to be placed in position by a power external to themselves. The same hypothesis is open to you now. But if in the case of crystals you have rejected this notion of an external architect, I think you are bound to reject it now, and to conclude that the molecules of the corn, also, are posited by the forces with which they act upon each other. It would be poor philosophy to invoke an external agent in the one case, and to reject it in the other.

Instead of cutting our grain of corn into slices and subjecting it to the action of polarised light, let us place it in the earth, and subject it to a certain degree of warmth. In other words, let the molecules, both of the corn and of the surrounding earth, be kept in that state of agitation which we call heat. Under these circumstances, the grain and the substances which surround it interact, and a definite molecular architecture is the result. A bud is formed; this bud reaches the surface, where it is exposed to the sun's rays, which are also to be regarded as a kind of vibratory motion. And as the motion of common heat, with which the grain and the substances surrounding it were first endowed, enabled the grain and these substances to exercise their mutual attractions and repulsions, and thus to coalesce in definite forms, so the specific motion of the sun's rays now enables the green bud to feed upon the carbonic acid and the aqueous vapour of the air. The bud appropriates those constituents of both for which it has an elective attraction, and permits the other constituent to resume its place in the atmosphere. Thus the architecture is carried on. Forces are active at the root, forces are active in the blade, the matter of the earth and the matter of the atmosphere are drawn towards the root and blade, and the plant augments in size. We have in succession the stalk, the ear, the full corn in the ear; the cycle of molecular action being completed by the production of grains, similar to that with which the process began.

Now there is nothing in this process which necessarily eludes the conceptive or imagining power of the human mind. An intellect the same in kind as our own would, if only sufficiently expanded, be able to follow the whole process from beginning to end. It would see every molecule placed in its position by the specific attractions and repulsions exerted between it and other molecules, the whole process, and its consummation, being an instance of the play of molecular force. Given the grain and its environment, the purely human intellect might, if sufficiently expanded, trace out *à priori* every step of the process of growth, and, by the application of purely mechanical principles, demonstrate that the cycle must end, as it is seen to end, in the reproduction of forms like that with which it began. A necessity rules here, similar to that which rules the planets in their circuits round the sun.

You will notice that I am stating the truth strongly, as at the beginning we agreed it should be stated. But I must go still further, and affirm that in the eye of science *the animal body* is just as much the product of molecular force as the stalk and ear of corn, or as the crystal of salt or sugar. Many of the parts of the body are obviously mechanical. Take the human heart, for example, with its system of valves, or take the exquisite mechanism of the eye or hand. Animal heat, moreover, is the same in kind as the heat of a fire, being produced by the same chemical process. Animal motion, too, is as directly derived from the food of the animal, as the motion of Trevethyck's walking-engine from the fuel in its furnace. As regards matter, the animal body creates nothing; as regards force, it creates nothing. Which of you by taking thought can add one cubit to his stature? All that has been said, then, regarding the plant, may be restated with regard to the animal. Every particle that enters into the composition of a muscle, a nerve, or a bone, has been placed in its position by molecular force. And unless the existence of law in these matters be denied, and the element of caprice introduced, we must conclude that, given the relation of any molecule of the body to its environment, its position in the body might be determined mathematically. Our difficulty is not with the *quality* of the problem, but with its *complexity*; and this difficulty might be met by the simple expansion of the faculties we now possess. Given this expansion, with the necessary molecular data, and the chick might be deduced as rigorously and as logically from the egg, as the existence of Neptune from the disturbances of Uranus, or as conical refraction from the undulatory theory of light.

You see I am not mincing matters, but avowing nakedly what many scientific thinkers more or less distinctly believe. The formation of a crystal, a plant, or an animal, is, in their eyes, a purely mechanical problem, which differs from the problems of ordinary mechanics, in the smallness of the masses, and the complexity of the processes involved. Here you have one half of our dual truth; let us now glance at the other half. Associated with this wonderful mechanism of the animal body we have phenomena no less certain than those of physics, but between which and the mechanism we discern no necessary connection. A man, for example, can say 'I feel, 'I think,' 'I love;' but how does *consciousness* infuse itself into the problem? The human brain is said to be the organ of thought and feeling: when we are hurt, the brain feels it; when we ponder, it is the brain that thinks; when our passions or affections are excited, it is through the instrumentality of the brain. Let us endeavour to be a little more precise here. I hardly imagine there exists a profound scientific thinker, who has reflected upon the subject, unwilling to admit the extreme probability of the hypothesis, that for every fact of consciousness, whether in the domain of sense, of thought, or of emotion, a definite molecular condition, of motion or structure, is set up in the brain; or who would be disposed even to deny that if the motion, or structure, be induced by internal causes instead of external, the effect on consciousness will be the same? Let any nerve, for example, be thrown by morbid action into the precise state of motion which would be communicated to it by the pulses of a heated body, surely that nerve will declare itself hot—the mind will accept the subjective intimation exactly as if it were objective. The retina may be excited by purely mechanical means. A blow on the eye causes a luminous flash, and the mere pressure of the finger on the external ball produces a star of light, which Newton compared to the circles on a peacock's tail. Disease makes people see visions and dream dreams; but, in all such cases, could we examine the organs implicated, we should, on philosophical grounds, expect to find them in that precise molecular condition which the real objects, if present, would superinduce.

The relation of physics to consciousness being thus invariable, it follows that, given the state of the brain, the corresponding thought or feeling might be inferred; or, given the thought or feeling, the corresponding state of the brain might be inferred. But how inferred? It would be at bottom not a case of logical inference at all, but of empirical association. You may reply, that many of the inferences of science are of this character—the inference, for example, that an electric current, of a given direction, will deflect a magnetic needle in a definite way. But the cases differ in this, that the passage from the current to the needle, if not demonstrable, is thinkable, and that we entertain no doubt as to the final mechanical solution of the problem. But the passage from the physics of the brain to the corresponding facts of consciousness is unthinkable. Granted that a definite thought, and a definite molecular action in the brain, occur simultaneously; we do not possess the intellectual organ, nor apparently any rudiment of the organ, which would enable us to pass, by a process of reasoning, from the one to the other. They appear together, but we do not know why. Were our minds and senses so expanded, strengthened, and illuminated, as to enable us to see and feel the very molecules of the brain; were we capable of following all their motions, all their groupings, all their electric discharges, if such there be; and were we intimately acquainted with the corresponding states of thought and feeling, we should be as far as ever from the solution of the problem, 'How are these physical processes connected with the facts of consciousness?' The chasm between the two classes of phenomena would still remain intellectually impassable. Let the consciousness of love, for example, be associated with a right-handed spiral motion of the molecules of the brain, and the consciousness of hate with a left-handed spiral motion. We should then know, when we love, that the motion is in one direction, and, when we hate, that the motion is in the other; but the 'WHY?' would remain as unanswerable as before.

In affirming that the growth of the body is mechanical, and that thought, as exercised by us, has its correlative in the physics of the brain, I think the position of the 'Materialist' is stated, as far as that position is a tenable one. I think the materialist will be able finally to maintain this position against all attacks; but I do not think, in the present condition of the human mind, that he can pass beyond this position. I do not think he is entitled to say that his molecular groupings, and motions, explain everything. In reality they explain nothing. The utmost he can affirm is the association of two classes of phenomena, of whose real bond of union he is in absolute ignorance. The problem of the connection of body and soul is as insoluble, in its modern form, as it was in the pre-scientific ages. Phosphorus is known to enter into the composition of the human brain, and a trenchant German writer has exclaimed, 'Ohne Phosphor, kein Gedanke!' That may or may not be the case; but even if we knew it to be the case, the knowledge would not lighten our darkness. On both sides of the zone here assigned to the materialist he is equally helpless. If you ask him whence is this 'Matter' of which we have been discoursing—who or what divided it into molecules, who or what impressed upon them this necessity of running into organic forms—he has no answer. Science is mute in reply to these questions. But if the materialist is confounded and science rendered dumb, who else is prepared with a solution? To whom has this arm of the Lord been revealed? Let us lower our heads, and acknowledge our ignorance, priest and philosopher, one and all.

Perhaps the mystery may resolve itself into knowledge at some future day. The process of things upon this earth has been one of amelioration. It is a long way from the Iguanodon and his contemporaries, to the President and Members of the British Association. And whether we regard the improvement from the scientific or from the theological point of view—as the result of progressive development, or of successive exhibitions of creative energy—neither view entitles us to assume that man's

Newton. For a time, Mr. Bain became my principal companion. I found him learned and practical, shining generally with a dry light, but exhibiting at times a flush of emotional strength, which proved that even logicians share the common fire of humanity. He interested me most when he became the mirror of my own condition. Neither intellectually nor socially is it good for man to be alone, and the griefs of thought are more patiently borne when we find that they have been experienced by another. From certain passages in his book I could infer that Mr. Bain was no stranger to such sorrows. Take this as an illustration. Speaking of the ebb of intellectual force, which we all from time to time experience, Mr. Bain says: 'The uncertainty where to look for the next opening of discovery brings the pain of conflict and the debility of indecision.' These words have in them the true ring of personal experience. The action of the investigator is periodic. He grapples with a subject of enquiry, wrestles with it, overcomes it, exhausts, it may be, both himself and it for the time being. He breathes a space, and then renews the struggle in another field. Now this period of halting between two investigations is not always one of pure repose. It is often a period of doubt and discomfort—of gloom and ennui. 'The uncertainty where to look for the next opening of discovery brings the pain of conflict and the debility of indecision.' Such was my precise condition in the Alps this year; and it was under these evil circumstances that I had to equip myself for the hour and the ordeal that are now come.

Gladly, however, as I should have seen this duty in other hands, it was not to be evaded. In some fashion or other—on the higher levels of thought, or on the flats of common-place—the task had to be accomplished. My case for a time resembled that of a sick doctor who had forgotten his art, and who sorely needed the prescription of a friend. Mr. Bain wrote one for me. 'Your present knowledge,' he said, 'must forge the links of connection between what has been already achieved and what is now required.'[1] In these words he admonished me to review the past, and recover from it the broken ends of former investigations. I tried to do so. Previous to going to Switzerland I had been thinking much of light and heat, of organic germs, atoms, comets, and skies. With one or another of these I now sought to re-form an alliance, and finally succeeded in establishing a kind of cohesion between thought and Light.

The disciplines of common life are, in great part, exercises in the relations of space, or in the mental grouping of bodies in space; and, by such exercises, the mind is, to some extent, prepared for the reception of physical conceptions. Assuming this preparation on your part, the wish grew within me to trace, and to enable you to trace, some of the more occult operations of the agent just referred to. I wished, if possible, to take you beyond the boundary of mere observation, into a region where things are intellectually discerned, and to show you there the hidden mechanism of optical action.

But how are those hidden things to be revealed? How are we to lay hold of the physical basis of light, since, like that of life itself, it lies entirely without the domain of the senses? Philosophers may be right in affirming that we cannot transcend experience; but we can, at all events, carry it a long way from its origin. We can also magnify, diminish, qualify, and combine experiences, so as to render them fit for purposes entirely new. Urged to the attempt by sensible phenomena, we find ourselves gifted with the power of forming mental images of the ultra-sensible; and by this power, when duly chastened and controlled, we can lighten the darkness which surrounds the world of the senses. There are Tories even in science who regard Imagination as a faculty to be feared and avoided rather than employed. They have observed its action in weak vessels, and are unduly impressed by its disasters. But they might with equal justice point to exploded boilers as an argument against the use of steam. Nourished by knowledge patiently won; bounded and conditioned by co-operant Reason; imagination becomes the prime mover of the physical discoverer. Newton's passage from a falling apple to a falling moon was, at the outset, a leap of the prepared imagination. In Faraday the exercise of this faculty preceded all his experiments, and its function has been impressively set forth by Brodie.[1] When William Thomson tries to place the ultimate particles of matter between his compass points, and to apply to them a scale of millimetres, it is an act of the scientific imagination. And in much that has been recently said about protoplasm and life we have the outgoings of this faculty guided and controlled by the known analogies of science. In fact, without this power, our knowledge of nature would be a mere tabulation of co-existences and sequences. We should still believe in the succession of day and night, of summer and winter; but the soul of Force would be dislodged from our universe; causal relations would disappear, and with them that science which is now binding the parts of nature to an organic whole.

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[1] 'Induction,' p. 422.

I should like to illustrate by a few simple instances the use that scientific men have already made of this power of imagination, and to indicate afterwards some of the further uses that they are likely to make of it. Let us begin with the rudimentary experiences. Observe the falling of heavy rain-drops into a tranquil pond. Each drop as it strikes the water becomes a centre of disturbance, from which a series of ring-ripples expand outwards. Gravity and inertia are the agents by which this wave-motion is produced, and a rough experiment will suffice to show that the rate of propagation does not amount to a foot a second. A series of slight mechanical shocks is experienced by a body plunged in the water, as the wavelets reach it in succession. But a finer motion is at the same time set up and propagated. If the head and ears be immersed in the water, as in an experiment of Franklin's, the shock of the drop is communicated to the auditory nerve—the *tick* of the drop is heard. Now, this sonorous impulse is propagated, not at the rate of a foot, but at the rate of 4,700 feet a second. In this case it is not the gravity but the *elasticity* of the water that is the urging force. Every liquid particle pushed against its neighbour delivers up its motion with extreme rapidity, and the pulse is propagated as a thrill. The incompressibility of water, as illustrated by the famous Florentine experiment, is a measure of its elasticity; and to the possession of this property, in so high a degree, the rapid transmission of a sound-pulse through water is to be ascribed.

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[1] At the outset of this discourse.

But water, as you know, is not necessary to the conduction of sound; air is its most common vehicle. And you know that when the air possesses the particular density and elasticity corresponding to the temperature of freezing water, the velocity of sound in it is 1,090 feet a second. It is almost exactly one-fourth of the velocity in water; the reason being that though the greater weight of the water tends to diminish the velocity, the enormous molecular elasticity of the liquid far more than atones for the disadvantage due to weight. By various contrivances we can compel the vibrations of the air to declare themselves; we know the length and frequency of the sonorous waves, and we have also obtained great mastery over the various methods by which the air is thrown into vibration. We know the phenomena and laws of vibrating rods, of organ-pipes, strings, membranes, plates, and bells. We can abolish one sound by another. We know the physical meaning of music and noise, of harmony and discord. In short, as regards sound in general, we have a very clear notion of the external physical processes which correspond to our sensations.

In the phenomena of sound, we travel a very little way from downright sensible experience. Still the imagination is to some extent exercised. The bodily eye, for example, cannot see the condensations and rarefactions of the waves of sound. We construct them in thought, and we believe as firmly in their existence as in that of the air itself. But now our experience is to be carried into a new region, where a new use is to be made of it. Having mastered the cause and mechanism of sound, we desire to know the cause and mechanism of light. We wish to extend our enquiries from the auditory to the optic nerve. There is in the human intellect a power of expansion—I might almost call it a power of creation—which is brought into play by the simple brooding upon facts. The legend of the Spirit brooding over chaos may have originated in a knowledge of this power. In the case now before us it has manifested itself by transplanting into space, for the purposes of light, an adequately modified form of the mechanism of sound. We know intimately whereon the velocity of sound depends. When we lessen the density of a medium, and preserve its elasticity constant, we augment the velocity. When we heighten the elasticity, and keep the density constant, we also augment the velocity. A small density, therefore, and a great elasticity, are the two things necessary to rapid propagation. Now light is known to move with the astounding velocity of 186,000 miles a second. How is such a velocity to be obtained?

By boldly diffusing in space a medium of the requisite tenuity and elasticity.

Let us make such a medium our starting-point, and, endowing it with one or two other necessary qualities, let us handle it in accordance with strict mechanical laws. Let us then carry our results from the world of theory into the world of sense, and see whether our deductions do not issue in the very phenomena of light which ordinary knowledge and skilled experiment reveal. If in all the multiplied varieties of these phenomena, including those of the most remote and entangled description, this fundamental conception always brings us face to face with the truth; if no contradiction to our deductions from it be found in external nature, but on all sides agreement and verification; if, moreover, as in the case of Conical Refraction and in other cases, it actually forces upon our attention phenomena which no eye had previously seen, and which no mind had previously imagined—such a conception must, we think, be something more than a mere figment of the scientific fancy. In forming it, that composite and creative power, in which reason and imagination are united, has, we believe, led us into a world not less real than that of the senses, and of which the world of sense itself is the suggestion and justification.

Far be it from me, however, to wish to fix you immovably in this or in any other theoretic conception. With all our belief of it, it will be well to keep the theory of a luminiferous aether plastic and capable of change. You may, moreover, urge that, although the phenomena occur *as if* the medium existed, the absolute demonstration of its existence is still wanting. Far be it from me to deny to this reasoning such validity as it may fairly claim. Let us endeavour by means of analogy to form a fair estimate of its force. You believe that in society you are surrounded by reasonable beings like yourself. You are, perhaps, as firmly convinced of this as of anything. What is your warrant for this conviction? Simply and solely this: your fellow-creatures behave as if they were reasonable; the hypothesis, for it is nothing more, accounts for the facts. To take an eminent example: you believe that our President is a reasonable being. Why? There is no known method of superposition by which any one of us can apply himself intellectually to another, so as to demonstrate coincidence as regards the possession of reason. If, therefore, you hold our President to be reasonable, it is because he behaves *as if* he were reasonable. As in the case of the aether, beyond the '*as if*' you cannot go. Nay, I should not wonder if a close comparison of the data on which both inferences rest, caused many respectable persons to conclude that the aether had the best of it.

This universal medium, this light-aether as it is called, is a vehicle, not an origin, of wave-motion. It receives and transmits, but it does not create. Whence does it derive the motions it conveys? For the most part from luminous bodies. By this motion of a luminous body I do not mean its sensible motion, such as the flicker of a candle, or the shooting out of red prominences from the limb of the sun. I mean an intestine motion of the atoms or molecules of the luminous body. But here a certain reserve is necessary. Many chemists of the present day refuse to speak of atoms and molecules as real things. Their caution leads them to stop short of the clear, sharp, mechanically intelligible atomic theory enunciated by Dalton, or any form of that theory, and to make the doctrine of 'multiple proportions' their intellectual bourne. I respect the caution, though I think it is here misplaced. The chemists who recoil from these notions of atoms and molecules accept, without hesitation, the Undulatory Theory of Light. Like you and me they one and all believe in an aether and its light-producing waves. Let us consider what this belief involves. Bring your imaginations once more into play, and figure a series of sound-waves passing through air. Follow them up to their origin, and what do you there find? A definite, tangible, vibrating body. It may be the vocal chords of a human being, it may be an organ-pipe, or it may be a stretched string. Follow in the same manner a train of aether-waves to their source; remembering at the same time that your aether is matter, dense, elastic, and capable of motions subject to, and determined by, mechanical laws. What then do you expect to find as the source of a series of aether-waves? Ask your imagination if it will accept a vibrating multiple proportion—a numerical ratio in a state of oscillation? I do not think it will. You cannot crown the edifice with this abstraction. The scientific imagination, which is here authoritative, demands, as the origin and cause of a series of aether-waves, a particle of vibrating matter quite as definite, though it may be excessively minute, as that which gives origin to a musical sound. Such a particle we name an atom or a molecule. I think the intellect, when focussed so as to give definition without penumbral haze, is sure to realise this image at the last.

With the view of preserving thought continuous throughout this discourse, and of preventing either failure of knowledge, or of memory, from causing any rent in our picture, I here propose to run rapidly over a bit of ground which is probably familiar to most of you, but which I am anxious to make familiar to you all. The waves generated in the aether by the swinging atoms of luminous bodies are of different lengths and amplitudes. The amplitude is the width of swing of the individual particles of the waves. In water-waves it is the height of the crest above the trough, while the length of the wave is the distance between two consecutive crests. The aggregate of waves emitted by the sun may be broadly divided into two classes: the one class competent, the other incompetent, to excite vision. But the light-producing waves differ markedly among themselves in size, form, and force. The length of the largest of these waves is about twice that of the smallest, but the amplitude of the largest is probably a hundred times that of the smallest. Now the force or energy of the wave, which, expressed with reference to sensation, means the intensity of the light, is proportional to the square of the amplitude. Hence the amplitude being one-hundredfold, the energy of the largest light-giving waves would be ten-thousandfold that of the smallest. This is not improbable. I use these figures not with a view to numerical accuracy, but to give you definite ideas of the differences that probably exist among the light-giving waves. And if we take the whole range of solar radiation into account—its non-visual as well as its visual waves—I think it probable that the force, or energy, of the largest wave is a million times that of the smallest.

Turned into their equivalents of sensation, the different light-waves produce different colours. Red, for example, is produced by the largest waves, violet by the smallest, while green is produced by a wave of intermediate length and amplitude. On entering from air into a more highly refracting substance, such as glass or water, or the sulphide of carbon, all the waves are retarded, but the smallest ones most. This furnishes a means of separating the different classes of waves from each other; in other words, of analysing the light. Sent through a refracting prism, the waves of the sun are turned aside in different degrees from their direct course, the red least, the violet most. They are virtually pulled asunder, and they paint upon a white screen placed to receive them 'the solar spectrum.' Strictly speaking, the spectrum embraces an infinity of colours; but the limits of language, and of our powers of distinction, cause it to be divided into seven segments: red, orange, yellow, green, blue, indigo, violet. These are the seven primary or prismatic colours.

Separately, or mixed in various proportions, the solar waves yield all the colours observed in nature and employed in art. Collectively, they give us the impression of whiteness. Pure unsifted solar light is white; and, if all the wave-constituents of such light be reduced in the same proportion, the light, though diminished in intensity, will still be white. The whiteness of Alpine snow with the sun shining upon it, is barely tolerable to the eye. The same snow under an overcast firmament is still white. Such a firmament enfeebles the light by reflecting it upwards; and when we stand above a cloud-field—on an Alpine summit, for instance, or on the top of Snowdon—and see, in the proper direction, the sun shining on the clouds below us, they appear dazzlingly white. Ordinary clouds, in fact, divide the solar light impinging on them into two parts—a reflected part and a transmitted part, in each of which the proportions of wave-motion which produce the impression of whiteness are sensibly preserved.

It will be understood that the condition of whiteness would fail if all the waves were diminished *equally*, or by the same absolute quantity. They must be reduced *proportionately*, instead of equally. If by the act of reflection the waves of red light are split into exact halves, then, to preserve the light white, the waves of yellow, orange, green, and blue must also be split into exact halves. In short, the reduction must take place, not by absolutely equal quantities, but by equal fractional parts. In white light the preponderance, as regards energy, of the larger over the smaller waves must always be immense.

Were the case otherwise, the visual correlative, *blue*, of the smaller waves would have the upper hand in our sensations.

Not only are the waves of aether reflected by clouds, by solids, and liquids, but when they pass from light air to dense, or from dense air to light, a portion of the wave-motion is always reflected. Now our atmosphere changes continually in density from top to bottom. It will help our conceptions if we regard it as made up of a series of thin concentric layers, or shells of air, each shell being of the same density throughout, a small and sudden change of density occurring in passing from shell to shell. Light would be reflected at the limiting surfaces of all these shells, and their action would be practically the same as that of the real atmosphere. And now I would ask your imagination to picture this act of reflection. What must become of the reflected light? The atmospheric layers turn their convex surfaces towards the sun; they are so many convex mirrors of feeble power; and you will immediately perceive that the light regularly reflected from these surfaces cannot reach the earth at all, but is dispersed in space. Light thus reflected cannot be the light of the sky.

But, though the sun's light is not reflected in this fashion from the aërial layers to the earth, there is indubitable evidence to show that the light of our firmament is reflected light. Proofs of the most cogent description could be here adduced; but we need only consider that we receive light at the same time from all parts of the hemisphere of heaven. The light of the firmament comes to us across the direction of the solar rays, and even against the direction of the solar rays; and this lateral and opposing rush of wave-motion can only be due to the rebound of the waves from the air itself, or from something suspended in the air. It is also evident that, unlike the action of clouds, the solar light is not reflected by the sky in the proportions which produce white. The sky is blue, which indicates an excess of the shorter waves. In accounting for the colour of the sky, the first question suggested by analogy would undoubtedly be, Is not the air blue? The blueness of the air has, in fact, been given as a solution of the blueness of the sky. But how, if the air be blue, can the light of sunrise and sunset, which travels through vast distances of air, be yellow, orange, or even red? The passage of white solar light through a blue medium could by no possibility redden the light. The hypothesis of a blue air is therefore untenable. In fact the agent, whatever it is, which sends us the light of the sky, exercises in so doing a dichroitic action. The light reflected is blue, the light transmitted is orange or red. A marked distinction is thus exhibited between the matter of the sky, and that of an ordinary cloud, which exercises no such dichroitic action.

By the scientific use of the imagination we may penetrate this mystery also. The cloud takes no note of size on the part of the waves of aether, but reflects them all alike. It exercises no selective action. Now the cause of this may be that the cloud particles are so large, in comparison with the waves of aether, as to reflect them all indifferently. A broad cliff reflects an Atlantic roller as easily as a ripple produced by a sea-bird's wing; and, in the presence of large reflecting surfaces, the existing differences of magnitude among the waves of aether may disappear. But supposing the reflecting particles, instead of being very large, to be very small in comparison with the size of the waves. In this case, instead of the whole wave being fronted and thrown back, a small portion only is shivered off. The great mass of the wave passes over such a particle without reflection. Scatter, then, a handful of such minute foreign particles in our atmosphere, and set imagination to watch their action upon the solar waves. Waves of all sizes impinge upon the particles, and you see at every collision a portion of the impinging wave struck off; all the waves of the spectrum, from the extreme red to the extreme violet, being thus acted upon.

Remembering that the red waves stand to the blue much in the relation of billows to ripples, we have to consider whether those extremely small particles are competent to scatter all the waves in the same proportion. If they be not—and a little reflection will make it clear that they are not—the production of colour must be an incident of the scattering. Largeness is a thing of relation; and the smaller the wave, the greater is the relative size of any particle on which the wave impinges, and the greater also the ratio of the scattered portion of the wave, to the total wave. A pebble, placed in the way of the ring-ripples produced by heavy rain-drops on a tranquil pond, will scatter a large fraction of each ripple, while the fractional part of a larger wave thrown back by the same pebble might be infinitesimal. Now we have already made it clear to our minds that to preserve the solar light white, its constituent proportions must not be altered; but in the act of division performed by these very small particles the proportions *are* altered; an undue fraction of the smaller waves is scattered by the particles, and, as a consequence in the scattered light, blue will be the predominant colour. The other colours of the spectrum must, to some extent, be associated with the blue. They are not absent, but deficient. We ought, in fact, to have them all, but in diminishing proportions, from the violet to the red.

We have here presented a case to the imagination, and, assuming the undulatory theory to be a reality, we have, I think, fairly reasoned our way to the conclusion, that were particles, small in comparison to the size of the aether waves, sown in our atmosphere, the light scattered by those particles would be exactly such as we observe in our azure skies. When this light is analysed, all the colours of the spectrum are found, and they are found in the proportions indicated by our conclusion.

Let us now turn our attention to the light which passes unscattered among the particles. How must it be finally affected? By its successive collisions with the particles the white light is more and more robbed of its shorter waves; it therefore loses more and more of its due proportion of blue. The result may be anticipated. The transmitted light, where short distances are involved, will appear yellowish. But as the sun sinks towards the horizon the atmospheric distances increase, and consequently the number of the scattering particles. They abstract in succession the violet, the indigo, the blue, and even disturb the proportions of green. The transmitted light under such circumstances must pass from yellow through orange to red. This also is exactly what we find in nature. Thus, while the reflected light gives us at noon the deep azure of the Alpine skies, the transmitted light gives us at sunset the warm crimson of the Alpine snows. The phenomena certainly occur *as if* our atmosphere were a medium rendered slightly turbid by the mechanical suspension of exceedingly small foreign particles.

Here, as before, we encounter our sceptical '*as if*.' It is one of the parasites of science, ever at hand, and ready to plant itself and sprout, if it can, on the weak points of our philosophy. But a strong constitution defies the parasite, and in our case, as we question the phenomena, probability grows like growing health, until in the one the malady of doubt is completely extirpated. The first question that naturally arises is this: Can small particles be really proved to act in the manner indicated? No doubt of it. Each one of you can submit the question to an experimental test. Water will not dissolve resin, but spirit will dissolve it; and when spirit holding resin in solution is dropped into water, the resin immediately separates in solid particles, which render the water milky. The coarseness of this precipitate depends on the quantity of the dissolved resin. You can cause it to separate either in thick clots or in exceedingly fine particles. Professor Brücke has given us the proportions which produce particles particularly suited to our present purpose. One gramme of clean mastic is dissolved in eighty-seven grammes of absolute alcohol, and the transparent solution is allowed to drop into a beaker containing clear water, kept briskly stirred. An exceedingly fine precipitate is thus formed, which declares its presence by its action upon light. Placing a dark surface behind the beaker, and permitting the light to fall into it from the top or front, the medium is seen to be distinctly blue. It is not perhaps so perfect a blue as may be seen on exceptional days among the Alps, but it is a very fair sky-blue. A trace of soap in water gives a tint of blue. London, and I fear Liverpool, milk makes an approximation to the same colour, through the operation of the same cause; and Helmholtz has irreverently disclosed the fact that the deepest blue eye is simply a turbid medium.

The action of turbid media upon light was illustrated by Goethe, who, though unacquainted with the undulatory theory, was led by his experiments to regard the firmament as an illuminated turbid medium, with the darkness of space behind it. He describes glasses showing a bright yellow by transmitted, and a beautiful blue by reflected, light. Professor Stokes, who was probably the first to discern the real nature of the action of small particles on the waves of aether,[1] describes a glass of a similar kind.[2] Capital specimens of such glass are to be found at Salviati's, in St. James's Street. What artists call 'chill' is no doubt an effect of this description. Through the action of minute particles, the browns of a picture often present the appearance of the bloom of a plum. By rubbing the varnish with a silk handkerchief optical continuity is established and the chill disappears. Some years ago I witnessed Mr. Hirst experimenting at Zermatt on the turbid water of the Visp. When kept still for a day or so, the grosser matter sank, but the finer particles remained suspended, and gave a distinctly blue tinge to the water. The blueness of certain Alpine lakes has been shown to be in part due to this cause. Professor Roscoe has noticed several striking cases of a similar kind. In a very remarkable paper the late Principal Forbes showed that steam issuing from the safety-valve of a locomotive, when favourably observed, exhibits at a certain stage of its condensation the colours of the sky. It is blue by reflected light, and orange or red by transmitted light. The same effect as pointed out by Goethe, is to some extent exhibited by peat-smoke. More than ten years ago I amused myself at Killarney by observing, on a calm day, the straight smoke-columns rising from the cabin chimneys. It was easy to project the lower portion of a column against a dark pine, and its upper portion against a bright cloud. The smoke in the former case was blue, being seen mainly by reflected light; in the latter case it was reddish, being seen mainly by transmitted light. Such smoke was not in exactly the condition to give us the glow of the Alps, but it was a step in this direction. Brücke's fine precipitate above referred to looks yellowish by transmitted light; but, by duly strengthening the precipitate, you may render the white light of noon as ruby-coloured as the sun, when seen through Liverpool smoke, or upon Alpine horizons. I do not, however, point to the gross smoke arising from coal as an illustration of the action of small particles, because such smoke soon absorbs and destroys the waves of blue, instead of sending them to the eyes of the observer.

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[1] This is inferred from conversation. I am not aware that Professor Stokes has published anything upon the subject.

[2] This glass, by reflected light, had a colour 'strongly resembling that of a decoction of horse-chestnut bark.' Curiously enough Goethe refers to this very decoction: 'Man nehme einen Streifen frischer Rinde von der Rosskastanie, man stecke denselben in ein Glas Wasser, und in der kürzesten Zeit werden wir das vollkommenste Himmelblau entstehen sehen.'—Goethe's *Werke*, b. xxix. p. 24.

These multifarious facts, and numberless others which cannot now be referred to, are explained by reference to the single principle, that, where the scattering particles are small in comparison to the aethereal waves, we have in the reflected light a greater proportion of the smaller waves, and in the transmitted light a greater proportion of the larger waves, than existed in the original white light. The consequence, as regards sensation, is that in the one case blue is predominant, and in the other orange or red. Our best microscopes can readily reveal objects not more than $\frac{1}{50000}$th of an inch in diameter. This is less than the length of a wave of red light. Indeed a first-rate microscope would enable us to discern objects not exceeding in diameter the length of the smallest waves of the visible spectrum. By the microscope, therefore, we can test our particles. If they be as large as the light-waves they will infallibly be seen; and if they be not so seen, it is because they are smaller. I placed in the hands of our President a liquid containing Brücke's precipitate. The liquid was a milky blue, and Mr. Huxley applied to it his highest microscopic power. He satisfied me, at the time, that had particles of even $\frac{1}{1000000}$th of an inch in diameter existed in the liquid, they could not have escaped detection. But no particles were seen. Under the microscope the turbid liquid was not to be distinguished from distilled water.[1]

But we have it in our power to imitate, far more closely than we have hitherto done, the natural conditions of this problem. We can generate, in air, artificial skies, and prove their perfect identity with the natural one, as regards the exhibition of a number of wholly unexpected phenomena. By a continuous process of growth, moreover, we are able to connect sky-matter, if I may use the term, with molecular matter on the one side, and with molar matter, or matter in sensible masses, on the other. In illustration of this I will take an experiment suggested by some of my own researches, and described by M. Morren of Marseilles at the Exeter meeting of the British Association. Sulphur and oxygen combine to form sulphurous acid gas, two atoms of oxygen and one of sulphur constituting the molecule of sulphurous acid. It has been recently shown that waves of aether issuing from a strong source, such as the sun or the electric light, are competent to shake asunder the atoms of gaseous molecules. A chemist would call this, 'decomposition' by light; but it behoves us, who are examining the power and function of the imagination, to keep constantly before us the physical images which underlie our terms. Therefore I say, sharply and definitely, that the components of the molecules of sulphurous acid are shaken asunder by the aether-waves. Enclosing sulphurous acid in a suitable vessel, placing it in a dark room, and sending through it a powerful beam of light, we at first see nothing: the vessel containing the gas seems as empty as a vacuum. Soon, however, along the track of the beam a beautiful sky-blue colour is observed, which is due to light scattered by the liberated particles of sulphur. For a time the blue grows more intense; it then becomes whitish; and ends in a more or less perfect white. When the action is continued long enough, the tube is filled with a dense cloud of sulphur particles, which by the application of proper means may be rendered individually visible.[1]

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[1] Like Dr. Burdon Sanderson's 'pyrogen,' the particles of mastic passed, without sensible hindrance, through filtering-paper. By such filtering no freedom from suspended particles is secured. The application of a condensed beam to the filtrate renders this at once evident. 1875.

Here, then, our aether-waves untie the bond of chemical affinity, and liberate a body—sulphur—which at ordinary temperatures is a solid, and which therefore soon becomes an object of the senses. We have first of all the free atoms of sulphur, which are incompetent to stir the retina sensibly with scattered light. But these atoms gradually coalesce and form *particles*, which grow larger by continual accretion, until after a minute or two they appear as sky-matter. In this condition they are themselves invisible; but they send an amount of wave-motion to the retina, sufficient to produce the firmamental blue. The particles continue, or may be caused to continue, in this condition for a considerable time, during which no microscope can cope with them. But they grow slowly larger, and pass by insensible gradations into the state of *cloud*, when they can no longer elude the armed eye. Thus, without solution of continuity, we start with matter in the molecule, and end with matter in the mass; sky-matter being the middle term of the series of transformations.

Instead of sulphurous acid, we might choose a dozen other substances, and produce the same effect with all of them. In the case of some—probably in the case of all—it is possible to preserve matter in the firmamental condition for fifteen or twenty minutes under the continual operation of the light. During these fifteen or twenty minutes the particles constantly grow larger, without ever exceeding the size requisite to the production of the celestial blue. Now when two vessels are placed before us, each containing sky-matter, it is possible to state with great distinctness which vessel contains the largest particles. The eye is very sensitive to differences of light, when, as in our experiments, it is in comparative darkness, and the wave-motion thrown against the retina is small. The larger particles declare themselves by the greater whiteness of their scattered light. Call now to mind the observation, or effort at observation, made by our President, when he failed to distinguish the particles of mastic in Brücke's medium, and when you have done this, please follow me. A beam of light was permitted to act upon a certain vapour. In two minutes the azure appeared, but at the end of fifteen minutes it had not ceased to be azure. After fifteen minutes, for example, its colour, and some other phenomena, pronounced it to be a blue of distinctly smaller particles than those sought for in vain by Mr. Huxley. These particles, as already stated, must have been less than $\frac{1}{100000}$th of an inch in diameter. And now I want you to consider the following question: Here are particles which have been growing continually for fifteen minutes, and at the end of that time are demonstrably smaller than those which defied the microscope of Mr. Huxley—*What must have been the size of these particles at the beginning of their growth?* What notion can you form of the magnitude of such particles? The distances of stellar space give us simply a bewildering sense of vastness, without leaving any distinct impression on the mind; and the magnitudes with which we have here to do, bewilder us equally in the opposite direction.

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[1] M. Morren was mistaken in supposing that a modicum of sulphurous acid, in the drying tubes, had any share in the production of the 'actinic clouds' described [illegible]

We are dealing with infinitesimals, compared with which the test objects of the microscope are literally immense.

From their perviousness to stellar light, and other considerations, Sir John Herschel drew some startling conclusions regarding the density and weight of comets. You know that these extraordinary and mysterious bodies sometimes throw out tails 100,000,000 of miles in length, and 50,000 miles in diameter. The diameter of our earth is 8,000 miles. Both it and the sky, and a good portion of space beyond the sky, would certainly be included in a sphere 10,000 miles across. Let us fill a hollow sphere of this diameter with cometary matter, and make it our unit of measure. To produce a comet's tail of the size just mentioned, about 300,000 such measures would have to be emptied into space. Now suppose the whole of this stuff to be swept together, and suitably compressed, what do you suppose its volume would be? Sir John Herschel would probably tell you that the whole mass might be carted away, at a single effort, by one of your dray-horses. In fact, I do not know that he would require more than a small fraction of a horse-power to remove the cometary dust. After this, you will hardly regard as monstrous a notion I have sometimes entertained, concerning the quantity of matter in our sky. Suppose a shell to surround the earth at a distance which would place it beyond the grosser matter that hangs in the lower regions of the air—say at the height of the Matterhorn or Mont Blanc. Outside this shell we should have the deep blue firmament. Let the atmospheric space beyond the shell be swept clean, and the sky-matter properly gathered up. What would be its probable amount? I have sometimes thought that a lady's portmanteau would contain it all. I have thought that even a gentleman's portmanteau—possibly his snuff-box—might take it in. And, whether the actual sky be capable of this amount of condensation or not, I entertain no doubt that a sky quite as vast as ours, and as good in appearance, could be formed from a quantity of matter which might be held in the hollow of the hand.

Small in mass, the vastness in point of number of the particles of our sky may be inferred from the continuity of its light. It is not in broken patches, nor at scattered points, that the heavenly azure is revealed. To the observer on the summit of Mont Blanc, the blue is as uniform and coherent as if it formed the surface of the most close-grained solid. A marble dome would not exhibit a stricter continuity. And Mr. Glaisher will inform you, that if our hypothetical shell were lifted to twice the height of Mont Blanc above the earth's surface, we should still have the azure overhead. Everywhere through the atmosphere those sky-particles are strewn. They fill the Alpine valleys, spreading like a delicate gauze in front of the slopes of pine. They sometimes so swathe the peaks with light as to abolish their definition. This year I have seen the Weisshorn thus dissolved in opalescent air. By proper instruments the glare thrown from the sky-particles against the retina may be quenched, and then the mountain which it obliterated starts into sudden definition. Its extinction in front of a dark mountain resembles exactly the withdrawal of a veil. It is the light, then, taking possession of the eye, and not the particles acting as opaque bodies, that interferes with the definition. By day this light quenches the stars; even by moonlight it is able to exclude from vision all stars between the fifth and the eleventh magnitude. It may be likened to a noise, and the feebler stellar radiance to a whisper drowned by the noise.

What is the nature of the particles which shed this light? The celebrated De la Rive ascribes the haze of the Alps in fine weather to floating organic germs. Now the possible existence of germs in such profusion has been held up as an absurdity. It has been affirmed that they would darken the air, and on the assumed impossibility of their existence in the requisite numbers, without invasion of the solar light, an apparently powerful argument has been based by believers in spontaneous generation. Similar arguments have been used by the opponents of the germ theory of epidemic disease, who have triumphantly challenged an appeal to the microscope and the chemist's balance to decide the question. Such arguments, however, are founded on a defective acquaintance with the powers and properties of matter. Without committing myself in the least to De la Rive's notion, to the doctrine of spontaneous generation, or to the germ theory of disease, I would simply draw attention to the demonstrable fact, that, in the atmosphere, we have particles which defy both the microscope and the balance, which do not darken the air, and which exist, nevertheless, in multitudes sufficient to reduce to insignificance the Israelitish hyperbole regarding the sands upon the sea-shore.

The varying judgments of men on these and other questions may perhaps be, to some extent, accounted for by that doctrine of Relativity which plays so important a part in philosophy. This doctrine affirms that the impressions made upon us by any circumstance, or combination of circumstances, depend upon our previous state. Two travellers upon the same height, the one having ascended to it from the plain, the other having descended to it from a higher elevation, will be differently affected by the scene around them. To the one nature is expanding, to the other it is contracting, and feelings which have two such different antecedent states are sure to differ. In our scientific judgments the law of relativity may also play an important part. To two men, one educated in the school of the senses, having mainly occupied himself with observation; the other educated in the school of imagination as well, and exercised in the conceptions of atoms and molecules to which we have so frequently referred, a bit of matter, say $\frac{1}{50000}$th of an inch in diameter, will present itself differently. The one descends to it from his molar heights, the other climbs to it from his molecular low-lands. To the one it appears small, to the other large. So, also, as regards the appreciation of the most minute forms of life revealed by the microscope. To one of the men these naturally appear conterminous with the ultimate particles of matter; there is but a step from the atom to the organism. The other discerns numberless organic gradations between both. Compared with his atoms, the smallest vibrios and bacteria of the microscopic field are as behemoth and leviathan. The law of relativity may to some extent explain the different attitudes of two such persons with regard to the question of spontaneous generation. An amount of evidence which satisfies the one entirely fails to satisfy the other; and while to the one the last bold defence and startling expansion of the doctrine by Dr. Bastian will appear perfectly conclusive, to the other it will present itself as imposing a profitless labour of demolition on subsequent investigators.

Let me say here that many of our physiological observers appear to form a very inadequate estimate of the distance which separates the microscopic from the molecular limit, and that, as a consequence, they sometimes employ a phraseology calculated to mislead. When, for example, the contents of a cell are described as perfectly homogeneous, or as absolutely structureless, because the microscope fails to distinguish any structure; or when two structures are pronounced to be without difference, because the microscope can discover none, then I think the microscope begins to play a mischievous part. A little consideration will make it plain that the microscope can have no voice in the question of germ structure. Distilled water is more perfectly homogeneous than any possible organic germ. What is it that causes the liquid to cease contracting at 39° Fahr., and to expand until it freezes? This is a structural process of which the microscope can take no note, nor is it likely to do so by any conceivable extension of its powers. Place distilled water in the field of an electro-magnet, and bring a microscope to bear upon it. Will any change be observed when the magnet is excited? Absolutely none; and still profound and complex changes have occurred. First of all, the particles of water have been rendered diamagnetically polar; and secondly, in virtue of the structure impressed upon it by the magnetic whirl of its molecules, the liquid twists a ray of light in a fashion perfectly determinate both as to quantity and direction.

Have the diamond, the amethyst, and the countless other crystals formed in the laboratories of nature and of man no structure? Assuredly they have; but what can the microscope make of it? Nothing. It cannot be too distinctly borne in mind that between the microscopic limit, and the true molecular limit, there is room for infinite permutations and combinations. It is in this region that the poles of the atoms are arranged, that tendency is given to their powers; so that when these poles and powers have free action, proper stimulus, and a suitable environment, they determine, first the germ, and afterwards the complete organism. This first marshalling of the atoms, on which all subsequent action depends, baffles a keener power than that of the microscope. When duly pondered, the complexity of the problem raises the doubt, not of the power of our instrument, for that is *nil*, but whether we ourselves possess the intellectual elements which will ever enable us to grapple with the ultimate structural energies of nature.[1]

In more senses than one Mr. Darwin has drawn heavily upon the scientific tolerance of his age. He has drawn heavily upon time in his development of species, and he has drawn adventurously upon matter in his theory of pangenesis. According to this theory, a germ already microscopic is a world of minor germs. Not only is the organism as a whole wrapped up in the germ, but every organ of the organism has there its special seed. This, I say, is an adventurous draft on the power of matter to divide itself and distribute its forces. But, unless we are perfectly sure that he is overstepping the bounds of reason, that he is unwittingly sinning against observed fact or demonstrated law—for a mind like that of Darwin can never sin wittingly against either fact or law—we ought, I think, to be cautious in limiting his intellectual horizon. If there be the least doubt in the matter, it ought to be given in favour of the freedom of such a mind. To it a vast possibility is in itself a dynamic power, though the possibility may never be drawn upon. It gives me pleasure to think that the facts and reasonings of this discourse tend rather towards the justification of Mr. Darwin, than towards his condemnation; that they tend rather to augment than to diminish the cubic space demanded by this soaring speculator. For they seem to show the perfect competence of matter and force, as regards divisibility and distribution, to bear the heaviest strain that he has hitherto imposed upon them.

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[1] 'In using the expression "one sort of living substance" I must guard against being supposed to mean that any kind of living protoplasm is homogeneous. Hyaline though it may appear, we are not at present able to assign any limit to its complexity of structure.—Burdon Sanderson, in the 'British Medical Journal,' January 16, 1875.

We have here scientific insight, and its correlative caution. In fact Dr. Sanderson's important researches are a continued illustration of the position laid down above.

In the case of Mr. Darwin, observation, imagination, and reason combined, have run back with wonderful sagacity and success over a certain length of the line of biological succession. Guided by analogy, in his 'Origin of Species' he placed at the root of life a primordial germ, from which he conceived the amazing richness and variety of the organisms now upon the earth's surface might be deduced. If this hypothesis were even true, it would not be final. The human mind would infallibly look behind the germ, and, however hopeless the attempt, would enquire into the history of its genesis. In this dim twilight of conjecture the searcher welcomes every gleam, and seeks to augment his light by indirect incidences. He studies the methods of nature in the ages and the worlds within his reach, in order to shape the course of speculation in the antecedent ages and worlds. And though the certainty possessed by experimental enquiry is here shut out, we are not left entirely without guidance. From the examination of the solar system, Kant and Laplace came to the conclusion that its various bodies once formed parts of the same undislocated mass; that matter in a nebulous form preceded matter in its present form; that as the ages rolled away, heat was wasted, condensation followed, planets were detached; and that finally the chief portion of the hot cloud reached, by self-compression, the magnitude and density of our sun. The earth itself offers evidence of a fiery origin; and in our day the hypothesis of Kant and Laplace receives the independent countenance of spectrum analysis, which proves the same substances to be common to the earth and sun.

Accepting some such view of the construction of our system as probable, a desire immediately arises to connect the present life of our planet with the past. We wish to know something of our remotest ancestry. On its first detachment from the central mass, life, as we understand it, could not have been present on the earth. How, then, did it come there? The thing to be encouraged here is a reverent freedom—a freedom preceded by the hard discipline which checks licentiousness in speculation—while the thing to be repressed, both in science and out of it, is dogmatism. And here I am in the hands of the meeting —willing to end, but ready to go on. I have no right to intrude upon you, unasked, the unformed notions which are floating like clouds, or gathering to more solid consistency, in the modern speculative scientific mind. But if you wish me to speak plainly, honestly, and undisputatiously, I am willing to do so. On the present occasion—

> You are ordained to call, and I to come.

Well, your answer is given, and I obey your call.

Two or three years ago, in an ancient London College, I listened to a discussion at the end of a lecture by a very remarkable man. Three or four hundred clergymen were present at the lecture. The orator began with the civilisation of Egypt in the time of Joseph; pointing out the very perfect organisation of the kingdom, and the possession of chariots, in one of which Joseph rode, as proving a long antecedent period of civilisation. He then passed on to the mud of the Nile, its rate of augmentation, its present thickness, and the remains of human handiwork found therein; thence to the rocks which bound the Nile valley, and which teem with organic remains. Thus in his own clear and admirable way he caused the idea of the world's age to expand itself indefinitely before the minds of his audience, and he contrasted this with the age usually assigned to the world. During his discourse he seemed to be swimming against a stream; he manifestly thought that he was opposing a general conviction. He expected resistance; so did I. But it was all a mistake: there was no adverse current, no opposing conviction, no resistance; merely here and there a half-humorous, but unsuccessful, attempt to entangle him in his talk. The meeting agreed with all that had been said regarding the antiquity of the earth and of its life. They had, indeed, known it all long ago, and they rallied the lecturer for coming amongst them with so stale a story. It was quite plain that this large body of clergymen, who were, I should say, the finest samples of their class, had entirely given up the ancient landmarks, and transported the conception of life's origin to an indefinitely distant past.

This leads us to the gist of our present enquiry, which is this: Does life belong to what we call matter, or is it an independent principle inserted into matter at some suitable epoch—say, when the physical conditions became such as to permit of the development of life? Let us put the question with the reverence due to a faith and culture in which we all were cradled, and which are the undeniable historic antecedents of our present enlightenment. I say, let us put the question reverently, but let us also put it clearly and definitely. There are the strongest grounds for believing that during a certain period of its history the earth was not, nor was it fit to be, the theatre of life. Whether this was ever a nebulous period, or merely a molten period, does not much matter; and if we revert to the nebulous condition, it is because the probabilities are really on its side. Our question is this: Did creative energy pause until the nebulous matter had condensed, until the earth had been detached, until the solar fire had so far withdrawn from the earth's vicinity as to permit a crust to gather round the planet? Did it wait until the air was isolated; until the seas were formed; until evaporation, condensation, and the descent of rain had begun; until the eroding forces of the atmosphere had weathered and decomposed the molten rocks so as to form soils; until the sun's rays had become so tempered by distance, and by waste, as to be chemically fit for the decompositions necessary to vegetable life? Having waited through those æons until the proper conditions had set in, did it send the fiat forth, 'Let there be Life!'? These questions define a hypothesis not without its difficulties, but the dignity of which was demonstrated by the nobleness of the men whom it sustained.

Modern scientific thought is called upon to decide between this hypothesis and another; and public thought generally will afterwards be called upon to do the same. But, however the convictions of individuals here and there may be influenced, the process must be slow and secular which commends the hypothesis of Natural Evolution to the public mind. For what are the core and essence of this hypothesis? Strip it naked, and you stand face to face with the notion that not alone the more ignoble forms of animalcular or animal life, not alone the nobler forms of the horse and lion, not alone the exquisite and wonderful mechanism of the human body, but that the human mind itself—emotion, intellect, will, and all their phenomena—were once latent in a fiery cloud. Surely the mere statement of such a notion is more than a refutation. But the hypothesis would probably go even farther than this. Many who hold it would probably assent to the position that, at the present moment, all our philosophy, all our poetry, all our science, and all our art—Plato, Shakspeare, Newton, and Raphael—are potential in the fires of the sun. We long to learn something of our origin. If the Evolution hypothesis be correct, even this unsatisfied yearning must have come to us across the ages which separate the unconscious primeval mist from the consciousness of to-day. I do not think that any holder of the Evolution hypothesis would say that I overstate or overstrain it in any way. I merely strip it of all vagueness, and bring before you, unclothed and unvarnished, the notions by which it must stand or fall.

Surely these notions represent an absurdity too monstrous to be entertained by any sane mind. But why are such notions absurd, and why should sanity reject them? The law of Relativity, of which we have previously spoken, may find its application here. These Evolution notions are absurd, monstrous, and fit only for the intellectual gibbet, in relation to the ideas concerning matter which were drilled into us when young. Spirit and matter have ever been presented to us in the rudest contrast, the one as all-noble, the other as all-vile. But is this correct? Upon the answer to this question all depends. Supposing that, instead of having the foregoing antithesis of spirit and matter presented to our youthful minds, we had been taught to regard them as equally worthy, and equally wonderful; to consider them, in fact, as two opposite faces of the self-same mystery. Supposing that in youth we had been impregnated with the notion of the poet Goethe, instead of the notion of the poet Young, looking at matter, not as brute matter, but as the 'living garment of God;' do you not think that under these altered circumstances the law of Relativity might have had an outcome different from its present one? Is it not probable that our repugnance to the idea of primeval union between spirit and matter might be considerably abated? Without this total revolution of the notions now prevalent, the Evolution hypothesis must stand condemned;

but in many profoundly thoughtful minds such a revolution has already taken place. They degrade neither member of the mysterious duality referred to; but they exalt one of them from its abasement, and repeal the divorce hitherto existing between both. In substance, if not in words, their position as regards the relation of spirit and matter is: 'What God hath joined together let not man put asunder.'

You have been thus led to the outer rim of speculative science, for beyond the nebulæ scientific thought has never hitherto ventured. I have tried to state that which I considered ought, in fairness, to be outspoken. I neither think this Evolution hypothesis is to be flouted away contemptuously, nor that it ought to be denounced as wicked. It is to be brought before the bar of disciplined reason, and there justified or condemned. Let us hearken to those who wisely support it, and to those who wisely oppose it; and let us tolerate those, whose name is legion, who try foolishly to do either of these things. The only thing out of place in the discussion is dogmatism on either side. Fear not the Evolution hypothesis. Steady yourselves, in its presence, upon that faith in the ultimate triumph of truth which was expressed by old Gamaliel when he said: 'If it be of God, ye cannot overthrow it; if it be of man, it will come to nought.' Under the fierce light of scientific enquiry, it is sure to be dissipated if it possess not a core of truth. Trust me, its existence as a hypothesis is quite compatible with the simultaneous existence of all those virtues to which the term 'Christian' has been applied. It does not solve—it does not profess to solve—the ultimate mystery of this universe. It leaves, in fact, that mystery untouched. For, granting the nebula and its potential life, the question, whence they came, would still remain to baffle and bewilder us. At bottom, the hypothesis does nothing more than 'transport the conception of life's origin to an indefinitely distant past.'

Those who hold the doctrine of Evolution are by no means ignorant of the uncertainty of their data, and they only yield to it a provisional assent. They regard the nebular hypothesis as probable, and, in the utter absence of any evidence to prove the act illegal, they extend the method of nature from the present into the past. Here the observed uniformity of nature is their only guide. Within the long range of physical enquiry, they have never discerned in nature the insertion of caprice. Throughout this range, the laws of physical and intellectual continuity have run side by side. Having thus determined the elements of their curve in a world of observation and experiment, they prolong that curve into an antecedent world,[1] and accept as probable the unbroken sequence of development from the nebula to the present time. You never hear the really philosophical defenders of the doctrine of Uniformity speaking of *impossibilities* in nature. They never say, what they are constantly charged with saying, that it is impossible for the Builder of the universe to alter His work. Their business is not with the possible, but the actual—not with a world which *might* be, but with a world that *is*. This they explore with a courage not unmixed with reverence, and according to methods which, like the quality of a tree, are tested by their fruits. They have but one desire—to know the truth. They have but one fear—to believe a lie. And if they know the strength of science, and rely upon it with unswerving trust, they also know the limits beyond which science ceases to be strong. They best know that questions offer themselves to thought, which science, as now prosecuted, has not even the tendency to solve.

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[1] See 'Belfast Address,' p. 507; and 'Apology,' p. 544.

They keep such questions open, and will not tolerate any unnecessary limitation of the horizon of their souls. They have as little fellowship with the atheist who says there is no God, as with the theist who professes to know the mind of God. 'Two things,' said Immanuel Kant, 'fill me with awe: the starry heavens, and the sense of moral responsibility in man.' And in his hours of health and strength and sanity, when the stroke of action has ceased, and the pause of reflection has set in, the scientific investigator finds himself overshadowed by the same awe. Breaking contact with the hampering details of earth, it associates him with a Power which gives fulness and tone to his existence, but which he can neither analyse nor comprehend.

Musings on the Matterhorn, July 27, 1868.

'Hacked and hurt by time, the aspect of the mountain from its higher crags saddened me. Hitherto the impression it made was that of savage strength; here we had inexorable decay. But this notion of decay implied a reference to a period when the Matterhorn was in the full strength of mountainhood. Thought naturally ran back to its remoter origin and sculpture. Nor did thought halt there, but wandered on through molten worlds to that nebulous haze which philosophers have regarded, and with good reason, as the proximate source of all material things. I tried to look at this universal cloud, containing within itself the prediction of all that has since occurred; I tried to imagine it as the seat of those forces whose action was to issue in solar and stellar systems, and all that they involve. Did that formless fog contain potentially the *sadness* with which I regarded

the Matterhorn? Did the *th*
to it simply return to its prin
not better recast our definitions
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[1] See p.

V.

VITALITY.

1865.

THE origin, growth, and energies of living things are subjects which have always engaged the attention of thinking men. To account for them it was usual to assume a special agent, free to a great extent from the limitations observed among the powers of inorganic nature. This agent was called the *vital force*; and, under its influence, plants and animals were supposed to collect their materials and to assume determinate forms. Within the last few years, however, our ideas of vital processes have undergone profound modifications; and the interest, and even disquietude, which the change has excited are amply evidenced by the discussions and protests which are now common regarding the phenomena of vitality. In tracing these phenomena, through all their modifications, the most advanced philosophers of the present day declare that they ultimately arrive at a single source of power, from which all vital energy is derived; and the disquieting circumstance is that this source is not the direct fiat of a supernatural agent, but a reservoir of what, if we do not accept the creed of Zoroaster, must be regarded as *inorganic* force. In short, it is considered as proved that all the energy which we derive from plants and animals is drawn from the sun.

A few years ago, when the sun was affirmed to be the source of life, nine out of ten of those who are alarmed by the form which this assertion has latterly assumed would have assented, in a general way, to its correctness. Their assent, however, was more poetic than scientific, and they were by no means prepared to see a rigid mechanical signification attached to their words. This, however, is the peculiarity of modern conclusions:—that there is no creative energy whatever in the vegetable or animal organism, but that all the power which we obtain from the muscles of man and animals, as much as that which we develop by the combustion of wood or coal, has been produced at the sun's expense. The sun is so much colder that we may have our fires; he is also so much colder that we may have our horse-racing and Alpine climbing. It is, for example, certain that the sun has been chilled to an extent capable of being accurately expressed in numbers, in order to furnish the power which lifted this year a certain number of tourists from the vale of Chamouni to the summit of Mont Blanc.

To most minds, however, the energy of light and heat presents itself as a thing totally distinct from ordinary mechanical energy. But either of them can be derived from the other. Wood can be raised by friction to the temperature of ignition; while by properly striking a piece of iron a skilful blacksmith can cause it to glow. Thus, by the rude agency of his hammer, he generates light and heat. This action, if carried far enough, would produce the light and heat of the sun. In fact the sun's light and heat have actually been referred to the fall of meteoric matter upon his surface; and whether the sun is thus supported or not, it is perfectly certain that he *might be* thus supported. Whether, moreover, the whilom molten condition of our planet was, as supposed by eminent men, due to the collision of cosmic masses or not, it is perfectly certain that the molten condition *might be* thus brought about. If, then, solar light and heat can be produced by the impact of dead matter, and if from the light and heat thus produced we can derive the energies which we have been accustomed to call *vital*, it indubitably follows that vital energy may have a proximately mechanical origin.

In what sense, then, is the sun to be regarded as the origin of the energy derivable from plants and animals? Let us try to give an intelligible answer to this question. Water may be raised from the sea-level to a high elevation, and then permitted to descend. In descending it may be made to assume various forms—to fall in cascades, to spurt in fountains, to boil in eddies, or to flow tranquilly along a uniform bed. It may, moreover, be caused to set complex machinery in motion, to turn millstones, throw shuttles, work saws and hammers, and drive piles. But every form of power here indicated would be derived from the original power expended in raising the water to the height from which it fell. There is no energy *generated* by the machinery; the work performed by the water in descending is merely the parcelling out and distribution of the work expended in raising it. In precisely this sense is all the energy of plants and animals the parcelling out and distribution of a power originally exerted by the sun. In the case of the water, the source of the power consists in the forcible separation of a quantity of the liquid from a low level of the earth's surface, and its elevation to a higher position, the power thus expended being returned by the water in its descent. In the case of vital phenomena, the source of power consists in the forcible separation of the atoms of compound substances by the sun.[1] We name the force which draws the water earthward 'gravity,' and that which draws atoms together 'chemical affinity;' but these different names must not mislead us regarding the qualitative identity of the two forces. They are both *attractions*; and, to the intellect, the falling of carbon atoms against oxygen atoms is not more difficult of conception than the falling of water to the earth.

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[1] Referred to further in Arts. I., III., and IV., Part I. · and Art. VIII., Part II.

The building up of the vegetable, then, is effected by the sun, through the reduction of chemical compounds. The phenomena of animal life are more or less complicated reversals of these processes of reduction. We eat the vegetable, and we breathe the oxygen of the air; and in our bodies the oxygen, which had been lifted from the carbon and hydrogen by the action of the sun, again falls towards them, producing animal heat and developing animal forms. Through the most complicated phenomena of vitality this law runs :—the vegetable is produced while a weight rises, the animal is produced while a weight falls. But the question is not exhausted here. The water employed in our first illustration generates all the motion displayed in its descent, but the *form* of the motion depends on the character of the machinery interposed in the path of the water. In a similar way, the primary action of the sun's rays is qualified by the atoms and molecules among which their energy is distributed. Molecular forces determine the form which the solar energy will assume. In the separation of the carbon and oxygen this energy may be so conditioned as to result in one case in the formation of a cabbage, and in another case in the formation of an oak. So also, as regards the reunion of the carbon and the oxygen, the molecular machinery through which the combining energy acts may, in one case, weave the texture of a frog while in another it may weave the texture of a man.

The matter of the animal body is that of inorganic nature. There is no substance in the animal tissues which is not primarily derived from the rocks, the water, and the air. Are the forces of organic matter, then, different in kind from those of inorganic matter? The philosophy of the present day negatives the question. It is the compounding, in the organic world, of forces belonging equally to the inorganic, that constitutes the mystery and the miracle of vitality. Every portion of every animal body may be reduced to purely inorganic matter. A perfect reversal of this process of reduction would carry us from the inorganic to the organic; and such a reversal is at least conceivable. The tendency, indeed, of modern science is to break down the wall of partition between organic and inorganic, and to reduce both to the operation of forces which are the same in kind, but which are variously compounded.

Consider the question of personal identity, in relation to that of molecular form. Twenty-six years ago Mayer, of Heilbronn, with that power of genius which breathes large meanings into scanty facts, pointed out that the blood was 'the oil of the lamp of life,' the combustion of which, like that of coal in grosser cases, sustains muscular action. The muscles are the machinery by which the dynamic power of the blood is brought into play. Thus the blood is consumed. But the whole body, though more slowly than the blood, wastes also, so that after a certain number of years it is entirely renewed. How is the sense of personal identity maintained across this flight of molecules? To man, as we know him, matter is necessary to consciousness; but the matter of any period may be all changed, while consciousness exhibits no solution of continuity. Like changing sentinels, the oxygen, hydrogen, and carbon that depart, seem to whisper their secret to their comrades that arrive, and thus, while the Non-ego shifts, the Ego remains intact. Constancy of form in the grouping of the molecules, and not constancy of the molecules themselves, is the correlative of this constancy of perception. Life is a *wave* which in no two consecutive moments of its existence is composed of the same particles.

Supposing, then, the molecules of the human body, instead of replacing others, and thus renewing a pre-existing form, to be gathered first hand from nature and put together in the same relative positions as those which they occupy in the body. Supposing them to have the selfsame forces and distribution of forces, the selfsame motions and distribution of motions—would this organised concourse of molecules stand before us as a sentient thinking being? There seems no valid reason to believe that it would not. Or, supposing a planet carved from the sun, set spinning round an axis, and revolving round the sun at a distance from him equal to that of our earth, would one of the consequences of its refrigeration be the development of organic forms? I lean to the affirmative. *Structural* forces are certainly in the mass, whether or not those forces reach to the extent of forming a plant or an animal. In an amorphous drop of water lie latent all the marvels of crystalline force; and who will set limits to the possible play of molecules in a cooling planet? If these statements startle, it is because matter has been defined and maligned by philosophers and theologians, who were equally unaware that it is, at bottom, essentially mystical and transcendental.

Questions such as these derive their present interest in great part from their audacity, which is sure, in due time, to disappear. And the sooner the public dread is abolished with reference to such questions the better for the cause of truth. As regards knowledge, physical science is polar. In one sense it knows, or is destined to know, everything. In another sense it knows nothing. Science understands much of this intermediate phase of things that we call nature, of which it is the product; but science knows nothing of the origin or destiny of nature. Who or what made the sun, and gave his rays their alleged power? Who or what made and bestowed upon the ultimate particles of matter their wondrous power of varied interaction? Science does not know: the mystery, though pushed back, remains unaltered. To many of us who feel that there are more things in heaven and earth than are dreamt of in the present philosophy of science, but who have been also taught, by baffled efforts, how vain is the attempt to grapple with the Inscrutable, the ultimate frame of mind is that of Goethe:

> Who dares to name His name,
> Or belief in Him proclaim,
> Veiled in mystery as He is, the All-enfolder?
> Gleams across the mind His light,
> Feels the lifted soul His might,
> Dare it then deny His reign, the All-upholder?

All the 'materialism' of the 'Belfast Address' seems to me to be concentrated in this somewhat ancient fragment. 1875.

VI.

ON PRAYER AS A FORM OF PHYSICAL ENERGY.

1872.

THE Editor of the 'Contemporary Review' is liberal enough to grant me space for some remarks upon a subject, a former reference to which has brought down upon me a considerable amount of animadversion.[1]

It may be interesting to some of my readers if I glance at a few cases illustrative of the history of the human mind, in relation to this and kindred questions. In the fourth century the belief in Antipodes was deemed unscriptural and heretical. The pious Lactantius was as angry with the people who held this notion as my censors are now with me, and quite as unsparing in his denunciations of their 'Monstrosities.' Lactantius was irritated because, in his mind, by education and habit, cosmogony and religion were indissolubly associated, and, therefore, simultaneously disturbed. In the early part of the seventeenth century the notion that the earth was fixed, and that the sun and stars revolved round it daily, was interwoven with religious feeling, the separation then attempted by Galileo arousing the animosity and kindling the persecution of the Church. Men still living can remember the indignation excited by the first revelations of geology regarding the age of the earth, the association between chronology and religion being for the time indissoluble. In our day, however, the best-informed theologians are prepared to admit that our views of the Universe and its Author are not impaired, but improved, by the abandonment of the Mosaic account of the Creation. Look, finally, at the excitement caused by the publication of the 'Origin of Species;' and compare it with the calm attendant on the appearance of the far more outspoken, and, from the old point of view, more impious, 'Descent of Man.'

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[1] I was made aware of this by the newspapers which reached me in Switzerland in July 1872.

Thus religion survives after the removal of what had been long considered essential to it. In our day the Antipodes are accepted; the fixity of the earth is given up; the period of Creation and the reputed age of the world are alike dissipated; Evolution is looked upon without terror, and other changes have occurred in the same direction too numerous to be dwelt upon here. In fact, from the earliest times to the present, religion has been undergoing a process of purification, freeing itself slowly and painfully from the physical errors which the active but uninformed intellect mingled with the aspirations of the soul. Some of us think that a final act of purification is needed, while others oppose this notion with the confidence and the warmth of ancient times. The bone of contention at present is *the physical value of prayer*. It is not my wish to excite surprise, much less to draw forth protest, by the employment of this phrase. I would simply ask any intelligent person to look the problem honestly in the face, and then to say whether, in the estimation of the great body of those who sincerely resort to it, prayer does not, at all events upon special occasions, invoke a Power which checks and augments the descent of rain, which changes the force and direction of winds, which affects the growth of corn, and the health of men and cattle—a Power, in short, which, when appealed to under pressing circumstances, produces the precise effects caused by physical energy in the ordinary course of things. To any person who deals sincerely with the subject, and refuses to blur his moral vision by intellectual subtleties, this, I think, will appear a true statement of the case.

It is under this aspect alone that the scientific student, so far as I represent him, has any wish to meddle with prayer. Forced upon his attention as a form of physical energy, or as the equivalent of such energy, he claims the right of subjecting it to those methods of examination from which all our present knowledge of the physical universe is derived. And if his researches lead him to a conclusion adverse to its claims—if his enquiries rivet him still closer to the philosophy implied in the words, 'He maketh His sun to shine on the evil and on the good, and sendeth rain upon the just and upon the unjust'—he contends only for the displacement of prayer, not for its extinction. He simply says, physical nature is not its legitimate domain.

This conclusion, moreover, must be based on pure physical evidence, and not on any inherent unreasonableness in the act of prayer. The theory that the system of nature is under the control of a Being who changes phenomena in compliance with the prayers of men, is, in my opinion, a perfectly legitimate one. It may of course be rendered futile by being associated with conceptions which contradict it; but such conceptions form no necessary part of the theory. It is a matter of experience that an earthly father, who is at the same time both wise and tender, listens to the requests of his children, and, if they do not ask amiss, takes pleasure in granting their requests. We know also that this compliance extends to the alteration, within certain limits, of the current of events on earth. With this suggestion offered by experience, it is no departure from scientific method to place behind natural phenomena a Universal Father, who, in answer to the prayers of His children, alters the currents of those phenomena. Thus far Theology and Science go hand in hand. The conception of an aether, for example, trembling with the waves of light, is suggested by the ordinary phenomena of wave-motion in water and in air; and in like manner the conception of personal volition in nature is suggested by the ordinary action of man upon earth. I therefore urge no *impossibilities*, though I am constantly charged with doing so. I do not even urge inconsistency, but, on the contrary, frankly admit that the theologian has as good a right to place his conception at the root of phenomena as I have to place mine.

But without *verification* a theoretic conception is a mere figment of the intellect, and I am sorry to find us parting company at this point. The region of theory, both in science and theology, lies behind the world of the senses, but the verification of theory occurs in the sensible world. To check the theory we have simply to compare the deductions from it with the facts of observation. If the deductions be in accordance with the facts, we accept the theory: if in opposition, the theory is given up. A single experiment is frequently devised, by which the theory must stand or fall. Of this character was the determination of the velocity of light in liquids, as a crucial test of the Emission Theory. According to it, light travelled faster in water than in air; according to the Undulatory Theory, it travelled faster in air than in water. An experiment suggested by Arago, and executed by Fizeau and Foucault, was conclusive against Newton's theory.

But, while science cheerfully submits to this ordeal, it seems impossible to devise a mode of verification of their theories which does not arouse resentment in theological minds. Is it that, while the pleasure of the scientific man culminates in the demonstrated harmony between theory and fact, the highest pleasure of the religious man has been already tasted in the very act of praying, prior to verification, any further effort in this direction being a mere disturbance of his peace? Or is it that we have before us a residue of that mysticism of the middle ages, so admirably described by Whewell—that 'practice of referring things and events not to clear and distinct notions, not to general rules capable of direct verification, but to notions vague, distant, and vast, which we cannot bring into contact with facts; as when we connect natural events with moral and historic causes.' 'Thus,' he continues, 'the character of mysticism is that it refers particulars, not to generalisations, homogeneous and immediate, but to such as are heterogeneous and remote; to which we must add that the process of this reference is not a calm act of the intellect, but is accompanied with a glow of enthusiastic feeling.'

Every feature here depicted, and some more questionable ones, have shown themselves of late; most conspicuously, I regret to say, in the 'leaders' of a weekly journal of considerable influence, and one, on many grounds, entitled to the respect of thoughtful men. In the correspondence, however, published by the same journal, are to be found two or three letters well calculated to correct the temporary flightiness of the journal itself.

It is not my habit of mind to think otherwise than solemnly of the feeling which prompts prayer. It is a power which I should like to see guided, not extinguished—devoted to practicable objects instead of wasted upon air. In some form or other, not yet evident, it may, as alleged, be necessary to man's highest culture. Certain it is that, while I rank many persons who resort to prayer low in the scale of being—natural foolishness, bigotry, and intolerance being in their case intensified by the notion that they have access to the ear of God—I regard others who employ it, as forming part of the very cream of the earth. The faith that adds to the folly and ferocity of the one, is turned to enduring sweetness, holiness, abounding charity, and self-sacrifice by the other. Religion, in fact, varies with the nature upon which it falls. Often unreasonable, if not contemptible, prayer, in its purer forms, hints at disciplines which few of us can neglect without moral loss. But no good can come of giving it a delusive value, by claiming for it a power in physical nature. It may strengthen the heart to meet life's losses, and thus indirectly promote physical well-being, as the digging of Æsop's orchard brought a treasure of fertility greater than the golden treasure sought. Such indirect issues we all admit; but it would be simply dishonest to affirm that it is such issues that are always in view. Here, for the present, I must end. I ask no space to reply to those railers who make such free use of the terms insolence, outrage, profanity, and blasphemy. They obviously lack the sobriety of mind necessary to give accuracy to their statements, or to render their charges worthy of serious refutation.

VII.

THE BELFAST ADDRESS.

1874.

AN impulse inherent in primeval man turned his thoughts and questionings betimes towards the sources of natural phenomena. The same impulse, inherited and intensified, is the spur of scientific action to-day. Determined by it, by a process of abstraction from experience we form physical theories which lie beyond the pale of experience, but which satisfy the desire of the mind to see every natural occurrence resting upon a cause. In forming their notions of the origin of things, our earliest historic (and doubtless, we might add, our prehistoric) ancestors pursued, as far as their intelligence permitted, the same course. They also fell back upon experience; but with this difference—that the particular experiences which furnished the weft and woof of their theories were drawn, not from the study of nature, but from what lay much closer to them—the observation of men. Their theories accordingly took an anthropomorphic form. To supersensual beings, which, 'however potent and invisible, were nothing but a species of human creatures, perhaps raised from among mankind, and retaining all human passions and appetites,'[1] were handed over the rule and governance of natural phenomena.

Tested by observation and reflection, these early notions failed in the long run to satisfy the more penetrating intellects of our race. Far in the depths of history we find men of exceptional power differentiating themselves from the crowd, rejecting these anthropomorphic notions, and seeking to connect natural phenomena with their physical principles. But, long prior to these purer efforts of the understanding, the merchant had been abroad, and rendered the philosopher possible, commerce had been developed, wealth amassed, leisure for travel and speculation secured, while races educated under different conditions, and therefore differently informed and endowed, had been stimulated and sharpened by mutual contact. In those regions where the commercial aristocracy of ancient Greece mingled with its eastern neighbours, the sciences were born, being nurtured and developed by free-thinking and courageous men. The state of things to be displaced may be gathered from a passage of Euripides quoted by Hume. 'There is nothing in the world; no glory, no prosperity. The gods toss all into confusion; mix everything with its reverse, that all of us, from our ignorance and uncertainty, may pay them the more worship and reverence.' Now, as science demands the radical extirpation of caprice, and the absolute reliance upon law in nature, there grew, with the growth of scientific notions, a desire and determination to sweep from the field of theory this mob of gods and demons, and to place natural phenomena on a basis more congruent with themselves.

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[1] Hume, 'Natural History of Religion.'

The problem which had been previously approached from above, was now attacked from below; theoretic effort passed from the super- to the sub-sensible. It was felt that to construct the universe in idea, it was necessary to have some notion of its constituent parts—of what Lucretius subsequently called the 'First Beginnings.' Abstracting again from experience, the leaders of scientific speculation reached at length the pregnant doctrine of atoms and molecules, the latest developments of which were set forth with such power and clearness at the last meeting of the British Association. Thought, no doubt, had long hovered about this doctrine before it attained the precision and completeness which it assumed in the mind of Democritus,[1] a philosopher who may well for a moment arrest our attention. 'Few great men,' says Lange, a non-materialist, in his excellent 'History of Materialism,' to the spirit and to the letter of which I am equally indebted, 'have been so despitefully used by history as Democritus. In the distorted images sent down to us through unscientific traditions, there remains of him almost nothing but the name of "the laughing philosopher," while figures of immeasurably smaller significance spread themselves out at full length before us.' Lange speaks of Bacon's high appreciation of Democritus—for ample illustrations of which I am indebted to my excellent friend Mr. Spedding, the learned editor and biographer of Bacon. It is evident, indeed, that Bacon considered Democritus to be a man of weightier metal than either Plato or Aristotle, though their philosophy 'was noised and celebrated in the schools, amid the din and pomp of professors.' It was not they, but Genseric and Attila and the barbarians, who destroyed the atomic philosophy. 'For, at a time when all human learning had suffered shipwreck, these planks of Aristotelian and Platonic philosophy, as being of a lighter and more inflated substance, were preserved and came down to us, while things more solid sank and almost passed into oblivion.'

The son of a wealthy father, Democritus devoted the whole of his inherited fortune to the culture of his mind. He travelled everywhere; visited Athens when Socrates and Plato were there, but quitted the city without making himself known. Indeed, the dialectic strife in which Socrates so much delighted, had no charm for Democritus, who held that 'the man who readily contradicts, and uses many words, is unfit to learn anything truly right.' He is said to have discovered and educated Protagoras the Sophist, being struck as much by the manner in which he, being a hewer of wood, tied up his faggots, as by the sagacity of his conversation. Democritus returned poor from his travels, was supported by his brother, and at length wrote his great work entitled 'Diakosmos,' which he read publicly before the people of his native town. He was honoured by his countrymen in various ways, and died serenely at a great age.

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[1] Born 460 B.C.

The principles enunciated by Democritus reveal his uncompromising antagonism to those who deduced the phenomena of nature from the caprices of the gods. They are briefly these: 1. From nothing comes nothing. Nothing that exists can be destroyed. All changes are due to the combination and separation of molecules. 2. Nothing happens by chance: every occurrence has its cause, from which it follows by necessity. 3. The only existing things are the atoms and empty space; all else is mere opinion. 4. The atoms are infinite in number, and infinitely various in form; they strike together, and the lateral motions and whirlings which thus arise are the beginnings of worlds. 5. The varieties of all things depend upon the varieties of their atoms, in number, size, and aggregation. 6. The soul consists of fine, smooth, round atoms, like those of fire. These are the most mobile of all: they interpenetrate the whole body, and in their motions the phenomena of life arise.

The first five propositions are a fair general statement of the atomic philosophy, as now held. As regards the sixth, Democritus made his finer atoms do duty for the nervous system, whose functions were then unknown.

The atoms of Democritus are individually without sensation; they combine in obedience to mechanical laws: and not only organic forms, but the phenomena of sensation and thought, are the result of their combination.

That great enigma, 'the exquisite adaptation of one part of an organism to another part, and to the conditions of life,' more especially the construction of the human body, Democritus made no attempt to solve. Empedocles, a man of more fiery and poetic nature, introduced the notion of love and hate among the atoms, to account for their combination and separation. Noticing this gap in the doctrine of Democritus, he struck in with the penetrating thought, linked, however, with some wild speculation, that it lay in the very nature of those combinations which were suited to their ends (in other words, in harmony with their environment) to maintain themselves, while unfit combinations, having no proper habitat, must rapidly disappear. Thus, more than 2,000 years ago, the doctrine of the 'survival of the fittest,' which in our day, not on the basis of vague conjecture, but of positive knowledge, has been raised to such extraordinary significance, had received at all events partial enunciation.[1]

Epicurus,[2] said to be the son of a poor schoolmaster at Samos, is the next dominant figure in the history of the atomic philosophy. He mastered the writings of Democritus, heard lectures in Athens, went back to Samos, and subsequently wandered through various countries. He finally returned to Athens, where he bought a garden, and surrounded himself by pupils, in the midst of whom he lived a pure and serene life, and died a peaceful death. Democritus looked to the soul as the ennobling part of man; even beauty, without understanding, partook of animalism. Epicurus also rated the spirit above the body; the pleasure of the body being that of the moment, while the spirit could draw upon the future and the past. His philosophy was almost identical with that of Democritus; but he never quoted either friend or foe. One main object of Epicurus was to free the world from superstition and the fear of death. Death he treated with indifference. It merely robs us of sensation. As long as we are, death is not; and when death is, we are not. Life has no more evil for him who has made up his mind that it is no evil not to live. He adored the gods, but not in the ordinary fashion. The idea of Divine power, properly purified, he thought an elevating one. Still he taught, 'Not he is godless who rejects the gods of the crowd, but rather he who accepts them.' The gods were to him eternal and immortal beings, whose blessedness excluded every thought of care or occupation of any kind. Nature pursues her course in accordance with everlasting laws, the gods never interfering. They haunt

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[1] 'Lange,' 2nd edit., p. 23.

[2] Born 342 B.C.

> The lucid interspace of world and world
> Where never creeps a cloud or moves a wind,
> Nor ever falls the least white star of snow,
> Nor ever lowest roll of thunder moans,
> Nor sound of human sorrow mounts to mar
> Their sacred everlasting calm.[1]

Lange considers the relation of Epicurus to the gods subjective; the indication, probably, of an ethical requirement of his own nature. We cannot read history with open eyes, or study human nature to its depths, and fail to discern such a requirement. Man never has been, and he never will be, satisfied with the operations and products of the Understanding alone; hence physical science cannot cover all the demands of his nature. But the history of the efforts made to satisfy these demands might be broadly described as a history of errors—the error, in great part, consisting in ascribing fixity to that which is fluent, which varies as we vary, being gross when we are gross, and becoming, as our capacities widen, more abstract and sublime. On one great point the mind of Epicurus was at peace. He neither sought nor expected, here or hereafter, any personal profit from his relation to the gods. And it is assuredly a fact, that loftiness and serenity of thought may be promoted by conceptions which involve no idea of profit of this kind. 'Did I not believe,' said a great man[1] to me once, 'that an Intelligence is at the heart of things, my life on earth would be intolerable.' The utterer of these words is not, in my opinion, rendered less but more noble by the fact, that it was the need of ethical harmony here, and not the thought of personal profit hereafter, that prompted his observation.

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[1] Tennyson's 'Lucretius.'

There are persons, not belonging to the highest intellectual zone, nor yet to the lowest, to whom perfect clearness of exposition suggests want of depth. They find comfort and edification in an abstract and learned phraseology. To such people Epicurus, who spared no pains to rid his style of every trace of haze and turbidity, appeared, on this very account, superficial. He had, however, a disciple who thought it no unworthy occupation to spend his days and nights in the effort to reach the clearness of his master, and to whom the Greek philosopher is mainly indebted for the extension and perpetuation of his fame. Some two centuries after the death of Epicurus, Lucretius[2] wrote his great poem, 'On the Nature of Things,' in which he, a Roman, developed with extraordinary ardour the philosophy of his Greek predecessor. He wishes to win over his friend Memnius to the school of Epicurus; and although he has no rewards in a future life to offer, although his object appears to be a purely negative one, he addresses his friend with the heat of an apostle. His object, like that of his great forerunner, is the destruction of superstition; and considering that men in his day trembled before every natural event as a direct monition from the gods, and that everlasting torture was also in prospect, the freedom aimed at by Lucretius might be deemed a positive good. 'This terror,' he says, 'and darkness of mind, must be dispelled, not by the rays of the sun and glittering shafts of day, but by the aspect and the law of nature.' He refutes the notion that anything can come out of nothing, or that what is once begotten can be recalled to nothing. The first beginnings, the atoms, are indestructible, and into them all things can be resolved at last. Bodies are partly atoms and partly combinations of atoms; but the atoms nothing can quench. They are strong in solid singleness, and, by their denser combination, all things can be closely packed and exhibit enduring strength. He denies that matter is infinitely divisible. We come at length to the atoms, without which, as an imperishable substratum, all order in the generation and development of things would be destroyed.

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[1] Carlyle.

[2] Born 99 B.C.

The mechanical shock of the atoms being, in his view, the all-sufficient cause of things, he combats the notion that the constitution of nature has been in any way determined by intelligent design. The interaction of the atoms throughout infinite time rendered all manner of combinations possible. Of these, the fit ones persisted, while the unfit ones disappeared. Not after sage deliberation did the atoms station themselves in their right places, nor did they bargain what motions they should assume. From all eternity they have been driven together, and, after trying motions and unions of every kind, they fell at length into the arrangements out of which this system of things has been evolved. 'If you will apprehend and keep in mind these things, Nature, free at once, and rid of her haughty lords, is seen to do all things spontaneously of herself, without the meddling of the gods.'[1]

To meet the objection that his atoms cannot be seen, Lucretius describes a violent storm, and shows that the invisible particles of air act in the same way as the visible particles of water. We perceive, moreover, the different smells of things, yet never see them coming to our nostrils. Again, clothes hung up on a shore, which waves break upon, become moist, and then get dry if spread out in the sun, though no eye can see either the approach or the escape of the water-particles. A ring, worn long on the finger, becomes thinner; a water-drop hollows out a stone; the ploughshare is rubbed away in the field; the street-pavement is worn by the feet; but the particles that disappear at any moment we cannot see. Nature acts through invisible particles. That Lucretius had a strong scientific imagination the foregoing references prove. A fine illustration of his power, in this respect, is his explanation of the apparent rest of bodies whose atoms are in motion. He employs the image of a flock of sheep with skipping lambs, which, seen from a distance, presents simply a white patch upon the green hill, the jumping of the individual lambs being quite invisible.

His vaguely grand conception of the atoms falling eternally through space, suggested the nebular hypothesis to Kant, its first propounder. Far beyond the limits of our visible world are to be found atoms innumerable, which have never been united to form bodies, or which, if once united, have been again dispersed—falling silently through immeasurable intervals of time and space. As everywhere throughout the All the same conditions are repeated, so must the phenomena be repeated also. Above us, below us, beside us, therefore, are worlds without end; and this, when considered, must dissipate every thought of a deflection of the universe by the gods. The worlds come and go, attracting new atoms out of limitless space, or dispersing their own particles. The reputed death of Lucretius, which forms the basis of Mr. Tennyson's noble poem, is in strict accordance with his philosophy, which was severe and pure.

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[1] Monro's translation. In his criticism of this work ('Contemporary Review,' 1867) Dr. Hayman does not appear to be aware of the really sound and subtile observations on which the reasoning of Lucretius, though erroneous, sometimes rests.

Still earlier than these three philosophers, and during the centuries between the first of them and the last, the human intellect was active in other fields than theirs. Pythagoras had founded a school of mathematics, and made his experiments on the harmonic intervals. The Sophists had run through their career. At Athens had appeared Socrates, Plato, and Aristotle, who ruined the Sophists, and whose yoke remains to some extent unbroken to the present hour. Within this period also the School of Alexandria was founded, Euclid wrote his 'Elements' and made some advance in optics. Archimedes had propounded the theory of the lever, and the principles of hydrostatics. Astronomy was immensely enriched by the discoveries of Hipparchus, who was followed by the historically more celebrated Ptolemy. Anatomy had been made the basis of scientific medicine; and it is said by Draper[1] that vivisection had begun. In fact, the science of ancient Greece had already cleared the world of the fantastic images of divinities operating capriciously through natural phenomena. It had shaken itself free from that fruitless scrutiny 'by the internal light of the mind alone,' which had vainly sought to transcend experience, and to reach a knowledge of ultimate causes. Instead of accidental observation, it had introduced observation with a purpose; instruments were employed to aid the senses; and scientific method was rendered in a great measure complete by the union of Induction and Experiment.

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[1] 'History of the Intellectual Development of Europe,' p. 295.

What, then, stopped its victorious advance? Why was the scientific intellect compelled, like an exhausted soil, to lie fallow for nearly two millenniums, before it could regather the elements necessary to its fertility and strength? Bacon has already let us know one cause; Whewell ascribes this stationary period to four causes—obscurity of thought, servility, intolerance of disposition, enthusiasm of temper; and he gives striking examples of each.[1] But these characteristics must have had their antecedents in the circumstances of the time. Rome, and the other cities of the Empire, had fallen into moral putrefaction. Christianity had appeared, offering the gospel to the poor, and, by moderation, if not asceticism of life, practically protesting against the profligacy of the age. The sufferings of the early Christians, and the extraordinary exaltation of mind which enabled them to triumph over the diabolical tortures to which they were subjected,[2] must have left traces not easily effaced. They scorned the earth, in view of that 'building of God, that house not made with hands, eternal in the heavens.' The Scriptures which ministered to their spiritual needs were also the measure of their Science. When, for example, the celebrated question of Antipodes came to be discussed, the Bible was with many the ultimate court of appeal. Augustine, who flourished A.D. 400, would not deny the rotundity of the earth; but he would deny the possible existence of inhabitants at the other side, 'because no such race is recorded in Scripture among the descendants of Adam.' Archbishop Boniface was shocked at the assumption of a 'world of human beings out of the reach of the means of salvation.' Thus reined in, Science was not likely to make much progress. Later on, the political and theological strife between the Church and civil governments, so powerfully depicted by Draper, must have done much to stifle investigation.

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[1] 'History of the Inductive Sciences,' vol. i.

[2] Depicted with terrible vividness in Renan's 'Antichrist.'

Whewell makes many wise and brave remarks regarding the spirit of the Middle Ages. It was a menial spirit. The seekers after natural knowledge had forsaken that fountain of living waters, the direct appeal to nature by observation and experiment, and given themselves up to the remanipulation of the notions of their predecessors. It was a time when thought had become abject, and when the acceptance of mere authority led, as it always does in science, to intellectual death. Natural events, instead of being traced to physical, were referred to moral, causes; while 'an exercise' of the phantasy, almost as degrading as the spiritualism of the present day, took the place of scientific speculation. Then came the mysticism of the Middle Ages, Magic, Alchemy, the Neoplatonic philosophy, with its visionary though sublime abstractions, which caused men to look with shame upon their own bodies, as hindrances to the absorption of the creature in the blessedness of the Creator. Finally came the Scholastic philosophy, a fusion, according to Lange, of the least mature notions of Aristotle with the Christianity of the west. Intellectual immobility was the result. As a traveller without a compass in a fog may wander long, imagining he is making way, and find himself after hours of toil at his starting-point, so the schoolmen, having 'tied and untied the same knots, and formed and dissipated the same clouds,' found themselves at the end of centuries in their old position.

With regard to the influence wielded by Aristotle in the Middle Ages, and which, to a less extent, he still wields, I would ask permission to make one remark. When the human mind has achieved greatness and given evidence of extraordinary power in one domain, there is a tendency to credit it with similar power in all other domains. Thus theologians have found comfort and assurance in the thought that Newton dealt with the question of revelation—forgetful of the fact, that the very devotion of his powers, through all the best years of his life, to a totally different class of ideas, not to speak of any natural disqualification, tended to render him less, instead of more, competent to deal with theological and historic questions. Goethe, starting from his established greatness as a poet, and indeed from his positive discoveries in Natural History, produced a profound impression among the painters of Germany, when he published his 'Farbenlehre,' in which he endeavoured to overthrow Newton's theory of colours. This theory he deemed so obviously absurd, that he considered its author a charlatan, and attacked him with a corresponding vehemence of language. In the domain of natural history Goethe had made really considerable discoveries; and we have high authority for assuming that, had he devoted himself wholly to that side of science, he might have reached, in it, an eminence comparable with that he attained as a poet. In sharpness of observation, in the detection of analogies apparently remote, in the classification and organisation of facts according to the analogies discerned, Goethe possessed extraordinary powers. These elements of scientific enquiry fall in with the disciplines of the poet. But, on the other hand, a mind thus richly endowed in the direction of natural history, may be almost shorn of endowment as regards the more strictly called physical and mechanical sciences. Goethe was in this condition. He could not formulate distinct mechanical conceptions; he could not see the force of mechanical reasoning; and, in regions where such reasoning reigns supreme, he became a mere *ignis fatuus* to those who followed him.

I have sometimes permitted myself to compare Aristotle with Goethe—to credit the Stagirite with an almost superhuman power of amassing and systematising facts, but to consider him fatally defective on that side of the mind, in respect to which incompleteness has been just ascribed to Goethe. Whewell refers the errors of Aristotle not to a neglect of facts, but to 'a neglect of the idea appropriate to the facts; the idea of Mechanical cause, which is Force, and the substitution of vague or inapplicable notions, involving only relations of space or emotions of wonder.' This is doubtless true; but the word 'neglect' implies mere intellectual misdirection, whereas in Aristotle, as in Goethe, it was not, I believe, misdirection, but sheer natural incapacity which lay at the root of his mistakes. As a physicist, Aristotle displayed what we should consider some of the worst attributes of a modern physical investigator—indistinctness of ideas, confusion of mind, and a confident use of language which led to the delusive notion that he had really mastered his subject, while he had, as yet, failed to grasp even the elements of it. He put words in the place of things, subject in the place of object. He preached Induction without practising it, inverting the true order of enquiry, by passing from the general to the particular, instead of from the particular to the general. He made of the universe a closed sphere, in the centre of which he fixed the earth, proving from general principles, to his own satisfaction and to that of the world for near 2,000 years, that no other universe was possible. His notions of motion were entirely unphysical. It was natural or unnatural, better or worse, calm or violent—no real mechanical conception regarding it lying at the bottom of his mind. He affirmed that a vacuum could not exist, and proved that if it did motion in it would be impossible. He determined *à priori* how many species of animals must exist, and shows on general principles why animals must have such and such parts. When an eminent contemporary philosopher, who is far removed from errors of this kind, remembers these abuses of the *à priori* method, he will be able to make allowance for the jealousy of physicists as to the acceptance of so-called *à priori* truths. Aristotle's errors of detail, as shown by Eucken and Lange, were grave and numerous. He affirmed that only in man we had the beating of the heart, that the left side of the body was colder than the right, that men have more teeth than women, and that there is an empty space at the back of every man's head.

There is one essential quality in physical conceptions, which was entirely wanting in those of Aristotle and his followers. I wish it could be expressed by a word untainted by its associations; it signifies a capability of being placed as a coherent picture before the mind. The Germans express the act of picturing by the word *vorstellen*, and the picture they call a *Vorstellung*. We have no word in English which comes nearer to our requirements than *Imagination*; and, taken with its proper limitations, the word answers very well. But, as just intimated, it is tainted by its associations, and therefore objectionable to some minds. Compare, with reference to this capacity of mental presentation, the case of the Aristotelian, who refers the ascent of water in a pump to Nature's abhorrence of a vacuum, with that of Pascal when he proposed to solve the question of atmospheric pressure by the ascent of the Puy de Dôme. In the one case the terms of the explanation refuse to fall into place as a physical image; in the other the image is distinct, the descent and rise of the barometer being clearly figured as the balancing of two varying and opposing pressures.

During the drought of the Middle Ages in Christendom, the Arabian intellect, as forcibly shown by Draper, was active. With the intrusion of the Moors into Spain, order, learning, and refinement took the place of their opposites. When smitten with disease, the Christian peasant resorted to a shrine, the Moorish one to an instructed physician. The Arabs encouraged translations from the Greek philosophers, but not from the Greek poets. They turned in disgust 'from the lewdness of our classical mythology, and denounced as an unpardonable blasphemy all connection between the impure Olympian Jove and the Most High God.' Draper traces still farther than Whewell the Arab elements in our scientific terms, and points out that the under garment of ladies retains to this hour its Arab name. He gives examples of what Arabian men of science accomplished, dwelling particularly on Alhazen, who was the first to correct the Platonic notion that rays of light are emitted by the eye. Alhazen discovered atmospheric refraction, and showed that we see the sun and the moon after they have set. He explained the enlargement of the sun and moon, and the shortening of the vertical diameters of both these bodies when near the horizon. He was aware that the atmosphere decreases in density with increase of elevation, and actually fixed its height at 58½ miles. In the 'Book of the Balance Wisdom,' he sets forth the connection between the weight of the atmosphere and its increasing density. He shows that a body will weigh differently in a rare and dense atmosphere, and he considers the force with which plunged bodies rise through heavier media. He understood the doctrine of the centre of gravity, and applied it to the investigation of balances and steelyards. He recognised gravity as a force, though he fell into the error of making it diminish simply as the distance, and of making it purely terrestrial. He knew the relation between the velocities, spaces, and times of falling bodies, and had distinct ideas of capillary attraction. He improved the hydrometer. The determinations of the densities of bodies, as given by Alhazen, approach very closely to our own. 'I join,' says Draper, in the pious prayer of Alhazen, 'that in the day of judgment the All-Merciful will take pity on the soul of Abur-Raihân, because he was the first of the race of men to construct a table of specific gravities.' If all this be historic truth (and I have entire confidence in Dr. Draper), well may he 'deplore the systematic manner in which the literature of Europe has contrived to put out of sight our scientific obligations to the Mahommedans.'[1]

The strain upon the mind during the stationary period towards ultra-terrestrial things, to the neglect of problems close at hand, was sure to provoke reaction. But the reaction was gradual; for the ground was dangerous, and a power at hand competent to crush the critic who went too far. To elude this power, and still allow opportunity for the expression of opinion, the doctrine of 'twofold truth' was invented, according to which an opinion might be held 'theologically,' and the opposite opinion 'philosophically.'[2] Thus, in the thirteenth century, the creation of the world in six days, and the unchangeableness of the individual soul, which had been so distinctly affirmed by St. Thomas Aquinas, were both denied philosophically, but admitted to be true as articles of the Catholic faith. When Protagoras uttered the maxim which brought upon him so much vituperation, that 'opposite assertions are equally true,' he simply meant to affirm men's differences to be so great, that what was subjectively true to the one might be subjectively untrue to the other. The great Sophist never meant to play fast and loose with the truth by saying that one of two opposite assertions, made by the same individual, could possibly escape being a lie. It was not 'sophistry,' but the dread of theologic vengeance, that generated this double dealing with conviction; and it is astonishing to notice what lengths were possible to men who were adroit in the use of artifices of this kind.

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[1] 'Intellectual Development of Europe,' p. 359.

[2] 'Lange,' 2nd edit. pp. 181, 182.

Towards the close of the stationary period a word-weariness, if I may so express it, took more and more possession of men's minds. Christendom had become sick of the School Philosophy and its verbal wastes, which led to no issue, but left the intellect in everlasting haze. Here and there was heard the voice of one impatiently crying in the wilderness, 'Not unto Aristotle, not unto subtle hypothesis, not unto church, Bible, or blind tradition, must we turn for a knowledge of the universe, but to the direct investigation of nature by observation and experiment.' In 1543 the epoch-making work of Copernicus on the paths of the heavenly bodies appeared. The total crash of Aristotle's closed universe, with the earth at its centre, followed as a consequence; and 'the earth moves' became a kind of watchword among intellectual freemen. Copernicus was Canon of the church of Frauenburg in the diocese of Ermeland. For three-and-thirty years he had withdrawn himself from the world, and devoted himself to the consolidation of his great scheme of the solar system. He made its blocks eternal; and even to those who feared it, and desired its overthrow, it was so obviously strong, that they refrained for a time from meddling with it. In the last year of the life of Copernicus his book appeared: it is said that the old man received a copy of it a few days before his death, and then departed in peace.

The Italian philosopher, Giordano Bruno, was one of the earliest converts to the new astronomy. Taking Lucretius as his exemplar, he revived the notion of the infinity of worlds; and, combining with it the doctrine of Copernicus, reached the sublime generalisation that the fixed stars are suns, scattered numberless through space, and accompanied by satellites, which bear the same relation to them that our earth does to our sun, or our moon to our earth. This was an expansion of transcendent import; but Bruno came closer than this to our present line of thought. Struck with the problem of the generation and maintenance of organisms, and duly pondering it, he came to the conclusion that Nature, in her productions, does not imitate the technic of man. Her process is one of unravelling and unfolding. The infinity of forms under which matter appears was not imposed upon it by an external artificer; by its own intrinsic force and virtue it brings these forms forth. Matter is not the mere naked, empty *capacity* which philosophers have pictured her to be, but the universal mother, who brings forth all things as the fruit of her own womb.

This outspoken man was originally a Dominican monk. He was accused of heresy and had to fly, seeking refuge in Geneva, Paris, England, and Germany. In 1592 he fell into the hands of the Inquisition at Venice. He was imprisoned for many years, tried, degraded, excommunicated, and handed over to the Civil power, with the request that he should be treated gently, and 'without the shedding of blood.' This meant that he was to be burnt; and burnt accordingly he was, on February 16, 1600. To escape a similar fate Galileo, thirty-three years afterwards, abjured upon his knees, with his hands upon the holy gospels, the heliocentric doctrine, which he knew to be true. After Galileo came Kepler, who from his German home defied the ultramontane power. He traced out from pre-existing observations the laws of planetary motion. Materials were thus prepared for Newton, who bound those empirical laws together by the principle of gravitation.

In the seventeenth century Bacon and Descartes, the restorers of philosophy, appeared in succession. Differently educated and endowed, their philosophic tendencies were different. Bacon held fast to Induction, believing firmly in the existence of an external world, and making collected experiences the basis of all knowledge. The mathematical studies of Descartes gave him a bias towards Deduction; and his fundamental principle was much the same as that of Protagoras, who made the individual man the measure of all things. 'I think, therefore I am,' said Descartes. Only his own identity was sure to him; and the full development of this system would have led to an idealism, in which the outer world would be resolved into a mere phenomenon of consciousness. Gassendi, one of Descartes's contemporaries, of whom we shall hear more presently, quickly pointed out that the fact of personal existence would be proved as well by reference to any other act, as to the act of thinking. I eat, therefore I am; or I love, therefore I am, would be quite as conclusive. Lichtenberg, indeed, showed that the very thing to be proved was inevitably postulated on the first two words, 'I think;' and it is plain that no inference from the postulate could, by any possibility, be stronger than the postulate itself.

But Descartes deviated strangely from the idealism implied in his fundamental principle. He was the first to reduce, in a manner eminently capable of bearing the test of mental presentation, vital phenomena to purely mechanical principles. Through fear or love, Descartes was a good churchman; he accordingly rejected the notion of an atom, because it was absurd to suppose that God, if He so pleased, could not divide an atom; he puts in the place of the atoms small round particles, and light splinters, out of which he builds the organism. He sketches with marvellous physical insight a machine, with water for its motive power, which shall illustrate vital actions. He has made clear to his mind that such a machine would be competent to carry on the processes of digestion, nutrition, growth, respiration, and the beating of the heart. It would be competent to accept impressions from the external sense, to store them up in imagination and memory, to go through the internal movements of the appetites and passions, and the external movements of the limbs. He deduces these functions of his machine from the mere arrangements of its organs, as the movement of a clock, or other automaton, is deduced from its weights and wheels. 'As far as these functions are concerned,' he says, 'it is not necessary to conceive any other vegetative or sensitive soul, nor any other principle of motion or of life, than the blood and the spirits agitated by the fire which burns continually in the heart, and which is in nowise different from the fires existing in inanimate bodies.' Had Descartes been acquainted with the steam-engine, he would have taken it, instead of a fall of water, as his motive power. He would have shown the perfect analogy which exists between the oxidation of the food in the body, and that of the coal in the furnace. He would assuredly have anticipated Mayer in calling the blood which the heart diffuses, 'the oil of the lamp of life;' deducing all animal motions from the combustion of this oil, as the motions of a steam-engine are deduced from the combustion of its coal. As the matter stands, however, and considering the circumstances of the time, the boldness, clearness, and precision with which Descartes grasped the problem of vital dynamics constitute a marvellous illustration of intellectual power.[1]

[1] See Huxley's admirable 'Essay on Descartes.' 'Lay Sermons,' pp. 364, 365.

Having formally acknowledged God as the great first cause, he immediately dropped the idea, applied the known laws of mechanics to the atoms, and deduced from them all vital phenomena. He defended Epicurus, and dwelt upon his purity, both of doctrine and of life. True he was a heathen, but so was Aristotle. Epicurus assailed superstition and religion, and rightly, because he did not know the true religion. He thought that the gods neither rewarded nor punished, and he adored them purely in consequence of their completeness: here we see, says Gassendi, the reverence of the child, instead of the fear of the slave. The errors of Epicurus shall be corrected, and the body of his truth retained. Gassendi then proceeds, as any heathen might do, to build up the world, and all that therein is, of atoms and molecules. God, who created earth and water, plants and animals, produced in the first place a definite number of atoms, which constituted the seed of all things. Then began that series of combinations and decompositions which now goes on, and which will continue in future. The principle of every change resides in matter. In artificial productions the moving principle is different from the material worked upon; but in nature the agent works within, being the most active and mobile part of the material itself. Thus this bold ecclesiastic, without incurring the censure of the church or the world, contrives to outstrip Mr. Darwin. The same cast of mind which caused him to detach the Creator from his universe, led him also to detach the soul from the body, though to the body he ascribes an influence so large as to render the soul almost unnecessary. The aberrations of reason were, in his view, an affair of the material brain. Mental disease is brain-disease; but then the immortal reason sits apart, and cannot be touched by the disease. The errors of madness are those of the instrument, not of the performer.

It may be more than a mere result of education, connecting itself, probably, with the deeper mental structure of the two men, that the idea of Gassendi, above enunciated, is substantially the same as that expressed by Professor Clerk Maxwell, at the close of the very able lecture delivered by him at Bradford last year. According to both philosophers, the atoms, if I understand aright, are *prepared materials*, which, formed once for all by the Eternal, produce by their subsequent interaction all the phenomena of the material world. There seems to be this difference, however, between Gassendi and Maxwell. The one *postulates*, the other *infers* his first cause. In his 'manufactured articles,' as he calls the atoms, Professor Maxwell finds the basis of an induction, which enables him to scale philosophic heights considered inaccessible by Kant, and to take the logical step from the atoms to their Maker.

Accepting here the leadership of Kant, I doubt the legitimacy of Maxwell's logic; but it is impossible not to feel the ethic glow with which his lecture concludes. There is, moreover, a very noble strain of eloquence in his description of the steadfastness of the atoms: 'Natural causes, as we know, are at work, which tend to modify, if they do not at length destroy, all the arrangements and dimensions of the earth and the whole solar system. But though in the course of ages catastrophes have occurred and may yet occur in the heavens, though ancient systems may be dissolved and new systems evolved out of their ruins, the molecules out of which these systems are built—the foundation stones of the material universe—remain unbroken and unworn.'

The atomic doctrine, in whole or in part, was entertained by Bacon, Descartes, Hobbes, Locke, Newton, Boyle, and their successors, until the chemical law of multiple proportions enabled Dalton to confer upon it an entirely new significance. In our day there are secessions from the theory, but it still stands firm. Loschmidt, Stoney, and Sir William Thomson have sought to determine the sizes of the atoms, or rather to fix the limits between which their sizes lie; while only last year the discourses of Williamson and Maxwell illustrate the present hold of the doctrine upon the foremost scientific minds. In fact, it may be doubted whether, wanting this fundamental conception, a theory of the material universe is capable of scientific statement.

Ninety years subsequent to Gassendi the doctrine of bodily instruments, as it may be called, assumed immense importance in the hands of Bishop Butler, who, in his famous 'Analogy of Religion,' developed, from his own point of view, and with consummate sagacity, a similar idea. The Bishop still influences superior minds; and it will repay us to dwell for a moment on his views. He draws the sharpest distinction between our real selves and our bodily instruments. He does not, as far as I remember, use the word soul, possibly because the term was so hackneyed in his day, as it had been for many generations previously. But he speaks of 'living powers,' 'perceiving or percipient powers,' 'moving agents,' 'ourselves,' in the same sense as we should employ the term soul. He dwells upon the fact that limbs may be removed and mortal diseases assail the body, the mind, almost up to the moment of death, remaining clear. He refers to sleep and to swoon, where the 'living powers' are suspended but not destroyed. He considers it quite as easy to conceive of existence out of our bodies as in them; that we may animate a succession of bodies, the dissolution of all of them having no more tendency to dissolve our real selves, or 'deprive us of living faculties —the faculties of perception and action—than the dissolution of any foreign matter which we are capable of receiving impressions from, or making use of for the common occasions of life.' This is the key of the Bishop's position: 'our organised bodies are no more a part of ourselves than any other matter around us.' In proof of this he calls attention to the use of glasses, which 'prepare objects' for the 'percipient power' exactly as the eye does. The eye itself is no more percipient than the glass; is quite as much the instrument of the true self, and also as foreign to the true self, as the glass is. 'And if we see with our eyes only in the same manner as we do with glasses, the like may justly be concluded from analogy of all our senses.'

Lucretius, as you are aware, reached a precisely opposite conclusion: and it certainly would be interesting, if not profitable, to us all, to hear what he would or could urge in opposition to the reasoning of the Bishop. As a brief discussion of the point will enable us to see the bearings of an important question, I will here permit a disciple of Lucretius to try the strength of the Bishop's position, and then allow the Bishop to retaliate, with the view of rolling back, if he can, the difficulty upon Lucretius.

The argument might proceed in this fashion:—

'Subjected to the test of mental presentation (*Vorstellung*), your views, most honoured prelate, would present to many minds a great, if not an insuperable, difficulty. You speak of "living powers," "percipient or perceiving powers," and "ourselves;" but can you form a mental picture of any of these, apart from the organism through which it is supposed to act? Test yourself honestly, and see whether you possess any faculty that would enable you to form such a conception. The true self has a local habitation in each of us; thus localised, must it not possess a form? If so, what form? Have you ever for a moment realised it? When a leg is amputated the body is divided into two parts; is the true self in both of them or in one? Thomas Aquinas might say in both; but not you, for you appeal to the consciousness associated with one of the two parts, to prove that the other is foreign matter. Is consciousness, then, a necessary element of the true self? If so, what do you say to the case of the whole body being deprived of consciousness? If not, then on what grounds do you deny any portion of the true self to the severed limb? It seems very singular that, from the beginning to the end of your admirable book (and no one admires its sober strength more than I do), you never once mention the brain or nervous system. You begin at one end of the body, and show that its parts may be removed without prejudice to the perceiving power. What if you begin at the other end, and remove, instead of the leg, the brain? The body, as before, is divided into two parts; but both are now in the same predicament, and neither can be appealed to to prove that the other is foreign matter. Or, instead of going so far as to remove the brain itself, let a certain portion of its bony covering be removed, and let a rhythmic series of pressures and relaxations of pressure be applied to the soft substance. At every pressure "the faculties of perception and of action" vanish; at every relaxation of pressure they are restored. Where, during the intervals of pressure, is the perceiving power? I once had the discharge of a large Leyden battery passed unexpectedly through me: I felt nothing, but was simply blotted out of conscious existence for a sensible interval. Where was my true self during that interval? Men who have recovered from lightning-stroke have been much longer in the same state; and indeed in cases of ordinary concussion of the brain, days may elapse during which no experience is registered in consciousness. Where is the man himself during the period of insensibility? You may say that I beg the question when I assume the man to have been unconscious, that he was really conscious all the time, and has simply forgotten what had occurred to him. In reply to this, I can only say that no one need shrink from the worst tortures that superstition ever invented, if only so felt and so remembered. I do not think your theory of instruments goes at all to the bottom of the matter. A telegraph-operator has his instruments, by means of which he converses with the world; our bodies possess a nervous system, which plays a similar part between the perceiving power and external things. Cut the wires of the operator, break his battery, demagnetise his needle; by this means you certainly sever his connection with the world; but, inasmuch as these are real instruments, their destruction does not touch the man who uses them. The operator survives, *and he knows that he survives.* What is it, I would ask, in the human system that answers to this conscious survival of the operator when the battery of the brain is so disturbed as to produce insensibility, or when it is destroyed altogether?

'Another consideration, which you may consider slight, presses upon me with some force. The brain may change from health to disease, and through such a change the most exemplary man may be converted into a debauchee or a murderer. My very noble and approved good master had, as you know, threatenings of lewdness introduced into his brain by his jealous wife's philter; and sooner than permit himself to run even the risk of yielding to these base promptings he slew himself. How could the hand of Lucretius have been thus turned against himself if the real Lucretius remained as before? Can the brain or can it not act in this distempered way without the intervention of the immortal reason? If it can, then it is a prime mover which requires only healthy regulation to render it reasonably self-acting, and there is no apparent need of your immortal reason at all. If it cannot, then the immortal reason, by its mischievous activity in operating upon a broken instrument, must have the credit of committing every imaginable extravagance and crime. I think, if you will allow me to say so, that the gravest consequences are likely to flow from your estimate of the body. To regard the brain as you would a staff or an eyeglass—to shut your eyes to all its mystery, to the perfect correlation of its condition and our consciousness, to the fact that a slight excess or defect of blood in it produces the very swoon to which you refer, and that in relation to it our meat, and drink, and air, and exercise, have a perfectly transcendental value and significance—to forget all this does, I think, open a way to innumerable errors in our habits of life, and may possibly, in some cases, initiate and foster that very disease, and consequent mental ruin, which a wiser appreciation of this mysterious organ would have avoided.'

I can imagine the Bishop thoughtful after hearing this argument. He was not the man to allow anger to mingle with the consideration of a point of this kind. After due reflection, and having strengthened himself by that honest contemplation of the facts which was habitual with him, and which includes the desire to give even adverse facts their due weight, I can suppose the Bishop to proceed thus: 'You will remember that in the "Analogy of Religion," of which you have so kindly spoken, I did not profess to prove anything absolutely, and that I over and over again acknowledged and insisted on the smallness of our knowledge, or rather the depth of our ignorance, as regards the whole system of the universe. My object was to show my deistical friends, who set forth so eloquently the beauty and beneficence of Nature and the Ruler thereof, while they had nothing but scorn for the so-called absurdities of the Christian scheme, that they were in no better condition then we were, and that, for every difficulty found upon our side, quite as great a difficulty was to be found upon theirs. I will now with your permission adopt a similar line of argument. You are a Lucretian, and from the combination and separation of insensate atoms deduce all terrestrial things, including organic forms and their phenomena. Let me tell you in the first instance how far I am prepared to go with you. I admit that you can build crystalline forms out of this play of molecular force; that the diamond, amethyst, and snow-star are truly wonderful structures which are thus produced. I will go farther and acknowledge that even a tree or flower might in this way be organised. Nay, if you can show me an animal without sensation, I will concede to you that it also might be put together by the suitable play of molecular force.

'Thus far our way is clear, but now comes my difficulty. Your atoms are individually without sensation, much more are they without intelligence. May I ask you, then, to try your hand upon this problem. Take your dead hydrogen atoms, your dead oxygen atoms, your dead carbon atoms, your dead nitrogen atoms, your dead phosphorus atoms, and all the other atoms, dead as grains of shot, of which the brain is formed. Imagine them separate and sensationless; observe them running together and forming all imaginable combinations. This, as a purely mechanical process, is *seeable* by the mind. But can you see, or dream, or in any way imagine, how out of that mechanical act, and from these individually dead atoms, sensation, thought, and emotion are to rise? Are you likely to extract Homer out of the rattling of dice, or the Differential Calculus out of the clash of billiard-balls? I am not all bereft of this *Vorstellungs-Kraft* of which you speak, nor am I, like so many of my brethren, a mere vacuum as regards scientific knowledge. I can follow a particle of musk until it reaches the olfactory nerve; I can follow the waves of sound until their tremors reach the water of the labyrinth, and set the otoliths and Corti's fibres in motion; I can also visualise the waves of aether as they cross the eye and hit the retina. Nay more, I am able to pursue to the central organ the motion thus imparted at the periphery, and to see in idea the very molecules of the brain thrown into tremors. My insight is not baffled by these physical processes. What baffles and bewilders me is the notion that from those physical tremors things so utterly incongruous with them as sensation, thought, and emotion can be derived. You may say, or think, that this issue of consciousness from the clash of atoms is not more incongruous than the flash of light from the union of oxygen and hydrogen. But I beg to say that it is. For such incongruity as the flash possesses is that which I now force upon your attention. The "flash" is an affair of consciousness, the objective counterpart of which is a vibration. It is a flash only by your interpretation. *You* are the cause of the apparent incongruity; and *you* are the thing that puzzles me. I need not remind you that the great Leibnitz felt the difficulty which I feel; and that to get rid of this monstrous deduction of life from death he displaced your atoms by his monads, which were more or less perfect mirrors of the universe, and out of the summation and integration of which he supposed all the phenomena of life—sentient, intellectual, and emotional—to arise.

'Your difficulty, then, as I see you are ready to admit, is quite as great as mine. You cannot satisfy the human understanding in its demand for logical continuity between molecular processes and the phenomena of consciousness. This is a rock on which Materialism must inevitably split whenever it pretends to be a complete philosophy of life. What is the moral, my Lucretian? You and I are not likely to indulge in ill-temper in the discussion of these great topics, where we see so much room for honest differences of opinion. But there are people of less wit or more bigotry (I say it with humility), on both sides, who are ever ready to mingle anger and vituperation with such discussions. There are, for example, writers of note and influence at the present day, who are not ashamed publicly to assume the "deep personal sin" of a great logician to be the cause of his unbelief in a theologic dogma.[1] And there are others who hold that we, who cherish our noble Bible, wrought as it has been into the constitution of our forefathers, and by inheritance into us, must necessarily be hypocritical and insincere. Let us disavow and discountenance such people, cherishing the unswerving faith that what is good and true in both our arguments will be preserved for the benefit of humanity, while all that is bad or false will disappear.'

I hold the Bishop's reasoning to be unanswerable, and his liberality to be worthy of imitation.

It is worth remarking that in one respect the Bishop was a product of his age. Long previous to his day the nature of the soul had been so favourite and general a topic of discussion, that, when the students of the Italian Universities wished to know the leanings of a new Professor, they at once requested him to lecture upon the soul. About the time of Bishop Butler the question was not only agitated but extended. It was seen by the clear-witted men who entered this arena, that many of their best arguments applied equally to brutes and men. The Bishop's arguments were of this character. He saw it, admitted it, took the consequence, and boldly embraced the whole animal world in his scheme of immortality.

Bishop Butler accepted with unwavering trust the chronology of the Old Testament, describing it as 'confirmed by the natural and civil history of the world, collected from common historians, from the state of the earth, and from the late inventions of arts and sciences.' These words mark progress; and they must seem somewhat hoary to the Bishop's successors of to-day. It is hardly necessary to inform you that since his time the domain of the naturalist has been immensely extended—the whole science of geology, with its astounding revelations regarding the life of the ancient earth, having been created. The rigidity of old conceptions has been relaxed, the public mind being rendered gradually tolerant of the idea that not for six thousand, nor for sixty thousand, nor for six thousand thousand, but for æons embracing untold millions of years, this earth has been the theatre of life and death. The riddle of the rocks has been read by the geologist and palæontologist, from sub-cambrian depths to the deposits thickening over the sea-bottoms of to-day. And upon the leaves of that stone book are, as you know, stamped the characters, plainer and surer than those formed by the ink of history, which carry the mind back into abysses of past time, compared with which the periods which satisfied Bishop Butler cease to have a visual angle.

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[1] This is the aspect under which the Editor of the 'Dublin Review' presents to his readers the memory of John Stuart Mill. I can only say, that I would as soon take my chance in the other world, in the company of the 'unbeliever,' as in that of his Jesuit detractor. In Dr. Ward we have an example of a wholesome and vigorous nature, soured and perverted by a poisonous creed.

The lode of discovery once struck, those petrified forms in which life was at one time active, increased to multitudes and demanded classification. They were grouped in genera, species, and varieties, according to the degree of similarity subsisting between them. Thus confusion was avoided, each object being found in the pigeon-hole appropriated to it and to its fellows of similar morphological or physiological character. The general fact soon became evident that none but the simplest forms of life lie lowest down; that, as we climb higher among the superimposed strata, more perfect forms appear. The change, however, from form to form was not continuous, but by steps—some small, some great. 'A section,' says Mr. Huxley, 'a hundred feet thick will exhibit at different heights a dozen species of Ammonite, none of which passes beyond its particular zone of limestone, or clay, into the zone below it, or into that above it.' In the presence of such facts it was not possible to avoid the question: Have these forms, showing, though in broken stages, and with many irregularities, this unmistakable general advance, been subjected to no continuous law of growth or variation? Had our education been purely scientific, or had it been sufficiently detached from influences which, however ennobling in another domain, have always proved hindrances and delusions when introduced as factors into the domain of physics, the scientific mind never could have swerved from the search for a law of growth, or allowed itself to accept the anthropomorphism which regarded each successive stratum as a kind of mechanic's bench for the manufacture of new species out of all relation to the old.

Biased, however, by their previous education, the great majority of naturalists invoked a special creative act to account for the appearance of each new group of organisms. Doubtless numbers of them were clear-headed enough to see that this was no explanation at all—that in point of fact it was an attempt, by the introduction of a greater difficulty, to account for a less. But, having nothing to offer in the way of explanation, they for the most part held their peace. Still the thoughts of reflecting men naturally and necessarily simmered round the question. De Maillet, a contemporary of Newton, has been brought into notice by Professor Huxley as one who 'had a notion of the modifiability of living forms.' In my frequent conversations with the late Sir Benjamin Brodie, a man of highly philosophic mind, he often drew my attention to the fact that, as early as 1794, Charles Darwin's grandfather was the pioneer of Charles Darwin.[1] In 1801, and in subsequent years, the celebrated Lamarck, who, through the vigorous exposition of his views by the author of the 'Vestiges of Creation,' rendered the public mind perfectly familiar with the idea of evolution, endeavoured to show the de velopment of species out of changes of habit and external condition. In 1813 Dr. Wells, the founder of our present theory of Dew, read before the Royal Society a paper in which, to use the words of Mr. Darwin, 'he distinctly recognises the principle of natural selection; and this is the first recognition that has been indicated.' The thoroughness and skill with which Wells pursued his work, and the obvious independence of his character, rendered him long ago a favourite with me; and it gave me the liveliest pleasure to alight upon this additional testimony to his penetration. Professor Grant, Mr. Patrick Matthew, Von Buch, the author of the 'Vestiges,' D'Halloy, and others,[1] by the enunciation of opinions more or less clear and correct, showed that the question had been fermenting long prior to the year 1858, when Mr. Darwin and Mr. Wallace simultaneously, but independently, placed their closely concurrent views before the Linnean Society.

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[1] 'Zoonomia,' vol. i. pp. 500–510.

These papers were followed in 1859 by the publication of the first edition of the 'Origin of Species.' All great things come slowly to the birth. Copernicus, as I informed you, pondered his great work for thirty-three years. Newton for nearly twenty years kept the idea of Gravitation before his mind; for twenty years also he dwelt upon his discovery of Fluxions, and doubtless would have continued to make it the object of his private thought, had he not found Leibnitz upon his track. Darwin for two-and-twenty years pondered the problem of the origin of species, and doubtless he would have continued to do so had he not found Wallace upon his track.[2] A concentrated, but full and powerful, epitome of his labours was the consequence. The book was by no means an easy one; and probably not one in every score of those who then attacked it, had read its pages through, or were competent to grasp their significance if they had. I do not say this merely to discredit them: for there were in those days some really eminent scientific men, entirely raised above the heat of popular prejudice, and willing to accept any conclusion that science had to offer, provided it was duly backed by fact and argument, who entirely mistook Mr. Darwin's views. In fact the work needed an expounder, and it found one in Mr. Huxley. I know nothing more admirable in the way of scientific exposition than those early articles of his on the origin of species. He swept the curve of discussion through the really significant points of the subject, enriched his exposition with profound original remarks and reflections, often summing up in a single pithy sentence an argument which a less compact mind would have spread over pages. But there is one impression made by the book itself which no exposition of it, however luminous, can convey; and that is the impression of the vast amount of labour, both of observation and of thought, implied in its production. Let us glance at its principles.

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[1] In 1855 Mr. Herbert Spencer ('Principles of Psychology,' 2nd edit. vol. i. p. 465) expressed 'the belief that life under all its forms has arisen by an unbroken evolution, and through the instrumentality of what are called natural causes.' This was my belief also at that time.

[2] The behaviour of Mr. Wallace in relation to this subject has been dignified in the highest degree.

It is conceded on all hands that what are called 'varieties' are continually produced. The rule is probably without exception. No chick, or child, is in all respects and particulars the counterpart of its brother and sister; and in such differences we have 'variety' incipient. No naturalist could tell how far this variation could be carried; but the great mass of them held that never, by any amount of internal or external change, nor by the mixture of both, could the offspring of the same progenitor so far deviate from each other as to constitute different species. The function of the experimental philosopher is to combine the conditions of Nature and to produce her results; and this was the method of Darwin.[1] He made himself acquainted with what could, without any manner of doubt, be done in the way of producing variation. He associated himself with pigeon-fanciers—bought, begged, kept, and observed every breed that he could obtain. Though derived from a common stock, the diversities of these pigeons were such that 'a score of them might be chosen which, if shown to an ornithologist, and he were told that they were wild birds, would certainly be ranked by him as well-defined species.' The simple principle which guides the pigeon-fancier, as it does the cattle-breeder, is the selection of some variety that strikes his fancy, and the propagation of this variety by inheritance. With his eye still directed to the particular appearance which he wishes to exaggerate, he selects it as it reappears in successive broods, and thus adds increment to increment until an astonishing amount of divergence from the parent type is effected. The breeder in this case does not produce the *elements* of the variation. He simply observes them, and by selection adds them together until the required result has been obtained. 'No man,' says Mr. Darwin, 'would ever try to make a fantail till he saw a pigeon with a tail developed in some slight degree in an unusual manner, or a pouter until he saw a pigeon with a crop of unusual size.' Thus nature gives the hint, man acts upon it, and by the law of inheritance exaggerates the deviation.

Having thus satisfied himself by indubitable facts that the organisation of an animal or of a plant (for precisely the same treatment applies to plants) is to some extent plastic, he passes from variation under domestication to variation under nature. Hitherto we have dealt with the adding together of small changes by the conscious selection of man. Can Nature thus select? Mr. Darwin's answer is, 'Assuredly she can.' The number of living things produced is far in excess of the number that can be supported; hence at some period or other of their lives there must be a struggle for existence; and what is the infallible result? If one organism were a perfect copy of the other in regard to strength, skill, and agility, external conditions would decide. But this is not the case. Here we have the fact of variety offering itself to nature, as in the former instance it offered itself to man; and those varieties which are least competent to cope with surrounding conditions, will infallibly give way to those that are most competent. To use a familiar proverb, the weakest comes to the wall. But the triumphant fraction again breeds to over-production, transmitting the qualities which secured its maintenance, but transmitting them in different degrees. The struggle for food again supervenes, and those to whom the favourable quality has been transmitted in excess, will triumph as before.

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[1] The first step only towards experimental demonstration has been taken. Experiments now begun might, a couple of centuries hence, furnish data of incalculable value, which ought to be supplied to the science of the future.

It is easy to see that we have here the addition of increments favourable to the individual, still more rigorously carried out than in the case of domestication; for not only are unfavourable specimens not selected by nature, but they are destroyed. This is what Mr. Darwin calls 'Natural Selection,' which 'acts by the preservation and accumulation of small inherited modifications, each profitable to the preserved being.' With this idea he interpenetrates and leavens the vast store of facts that he and others have collected. We cannot, without shutting our eyes through fear or prejudice, fail to see that Darwin is here dealing, not with imaginary, but with true causes; nor can we fail to discern what vast modifications may be produced by natural selection in periods sufficiently long. Each individual increment may resemble what mathematicians call a 'differential' (a quantity indefinitely small); but definite and great changes may obviously be produced by the integration of these infinitesimal quantities, through practically infinite time.

If Darwin, like Bruno, rejects the notion of creative power acting after human fashion, it certainly is not because he is unacquainted with the numberless exquisite adaptations, on which this notion of a supernatural Artificer has been founded. His book is a repository of the most startling facts of this description. Take the marvellous observation which he cites from Dr. Crüger, where a bucket with an aperture, serving as a spout, is formed in an orchid. Bees visit the flower: in eager search of material for their combs they push each other into the bucket, the drenched ones escaping from their involuntary bath by the spout. Here they rub their backs against the viscid stigma of the flower and obtain glue; then against the pollen-masses, which are thus stuck to the back of the bee and carried away. 'When the bee, so provided, flies to another flower, or to the same flower a second time, and is pushed by its comrades into the bucket, and then crawls out by the passage, the pollen-mass upon its back necessarily comes first into contact with the viscid stigma,' which takes up the pollen; and this is how that orchid is fertilised. Or take this other case of the *Catasetum*. 'Bees visit these flowers in order to gnaw the labellum; in doing this they inevitably touch a long, tapering, sensitive projection. This, when touched, transmits a sensation or vibration to a certain membrane, which is instantly ruptured, setting free a spring, by which the pollen-mass is shot forth like an arrow in the right direction, and adheres by its viscid extremity to the back of the bee.' In this way the fertilising pollen is spread abroad.

It is the mind thus stored with the choicest materials of the teleologist that rejects teleology, seeking to refer these wonders to natural causes. They illustrate, according to him, the method of nature, not the 'technic' of a man-like Artificer. The beauty of flowers is due to natural selection. Those that distinguish themselves by vividly contrasting colours from the surrounding green leaves are most readily seen, most frequently visited by insects, most often fertilised, and hence most favoured by natural selection. Coloured berries also readily attract the attention of birds and beasts, which feed upon them, spread their manured seeds abroad, thus giving trees and shrubs possessing such berries a greater chance in the struggle for existence.

With profound analytic and synthetic skill, Mr. Darwin investigates the cell-making instinct of the hive-bee. His method of dealing with it is representative. He falls back from the more perfectly to the less perfectly developed instinct—from the hive-bee to the humble bee, which uses its own cocoon as a comb, and to classes of bees of intermediate skill, endeavouring to show how the passage might be gradually made from the lowest to the highest. The saving of wax is the most important point in the economy of bees. Twelve to fifteen pounds of dry sugar are said to be needed for the secretion of a single pound of wax. The quantities of nectar necessary for the wax must therefore be vast; and every improvement of constructive instinct which results in the saving of wax is a direct profit to the insect's life. The time that would otherwise be devoted to the making of wax, is now devoted to the gathering and storing of honey for winter food. Mr. Darwin passes from the humble bee with its rude cells, through the Melipona with its more artistic cells, to the hive-bee with its astonishing architecture. The bees place themselves at equal distances apart upon the wax, sweep and excavate equal spheres round the selected points. The spheres intersect, and the planes of intersection are built up with thin laminæ. Hexagonal cells are thus formed.

This mode of treating such questions is, as I have said, representative. The expositor habitually retires from the more perfect and complex, to the less perfect and simple, and carries you with him through stages of *perfecting*—adds increment to increment of infinitesimal change, and in this way gradually breaks down your reluctance to admit that the exquisite climax of the whole could be a result of natural selection.

Mr. Darwin shirks no difficulty; and, saturated as the subject was with his own thought, he must have known, better than his critics, the weakness as well as the strength of his theory. This of course would be of little avail were his object a temporary dialectic victory, instead of the establishment of a truth which he means to be everlasting. But he takes no pains to disguise the weakness he has discerned; nay, he takes every pains to bring it into the strongest light. His vast resources enable him to cope with objections started by himself and others, so as to leave the final impression upon the reader's mind that, if they be not completely answered, they certainly are not fatal. Their negative force being thus destroyed, you are free to be influenced by the vast positive mass of evidence he is able to bring before you. This largeness of knowledge, and readiness of resource, render Mr. Darwin the most terrible of antagonists. Accomplished naturalists have levelled heavy and sustained criticisms against him—not always with the view of fairly weighing his theory, but with the express intention of exposing its weak points only. This does not irritate him. He treats every objection with a soberness and thoroughness, which even Bishop Butler might be proud to imitate, surrounding each fact with its appropriate detail, placing it in its proper relations, and usually giving it a significance which, as long as it was kept isolated, failed to appear. This is done without a trace of ill-temper. He moves over the subject with the passionless strength of a glacier; and the grinding of the rocks is not always without a counterpart in the logical pulverisation of the objector. But though in handling this mighty theme all passion has been stilled, there is an emotion of the intellect, incident to the discernment of new truth, which often colours and warms the pages of Mr. Darwin. His success has been great; and this implies not only the solidity of his work, but the preparedness of the public mind for such a revelation. On this head a remark of Agassiz impressed me more than anything else. Sprung from a race of theologians, this celebrated man combated to the last the theory of natural selection. One of the many times I had the pleasure of meeting him in the United States was at Mr. Winthrop's beautiful residence at Brookline, near Boston. Rising from luncheon, we all halted as if by common consent in front of a window, and continued there a discussion which had been started at table. The maple was in its autumn glory; and the exquisite beauty of the scene outside seemed, in my case, to interpenetrate without disturbance the intellectual action. Earnestly, almost sadly, Agassiz turned, and said to the gentlemen standing round, 'I confess that I was not prepared to see this theory received as it has been by the best intellects of our time. Its success is greater than I could have thought possible.'

In our day grand generalisations have been reached. The theory of the origin of species is but one of them. Another, of still wider grasp and more radical significance, is the doctrine of the Conservation of Energy, the ultimate philosophical issues of which are as yet but dimly seen—that doctrine which 'binds nature fast in fate' to an extent not hitherto recognised, exacting from every antecedent its equivalent consequent, from every consequent its equivalent antecedent, and bringing vital as well as physical phenomena under the dominion of that law of causal connection which, so far as the human understanding has yet pierced, asserts itself everywhere in nature. Long in advance of all definite experiment upon the subject, the constancy and indestructibility of matter had been affirmed; and all subsequent experience justified the affirmation. Mayer extended the attribute of indestructibility to force, applying it in the first instance to inorganic, and afterwards, with profound insight, to organic nature. The vegetable world, though drawing almost all its nutriment from invisible sources, was proved incompetent to generate anew either matter or force. Its matter is for the most part transmuted gas; its force transformed solar force. The animal world was proved to be equally uncreative, all its motive energies being referred to the combustion of its food. The activity of each animal, as a whole, was proved to be the transferred activity of its molecules. The muscles were shown to be stores of mechanical energy, potential until unlocked by the nerves, and then resulting in muscular contractions. The speed at which messages fly to and fro along the nerves was determined, and found to be, not as had been previously supposed, equal to that of light or electricity, but less than the speed of sound—less even than that of a flying eagle.

This was the work of the physicist: then came the conquests of the comparative anatomist and physiologist, revealing the structure of every animal, and the function of every organ in the whole biological series, from the lowest zoophyte up to man. The nervous system had been made the object of profound and continued study, the wonderful and, at bottom, entirely mysterious controlling power which it exercises over the whole organism, physical and mental, being recognised more and more. Thought could not be kept back from a subject so profoundly suggestive. Besides the physical life dealt with by Mr.

Darwin, there is a psychical life presenting similar gradations, and asking equally for a solution. How are the different grades and orders of Mind to be accounted for? What is the principle of growth of that mysterious power which on our planet culminates in Reason? These are questions which, though not thrusting themselves so forcibly upon the attention of the general public, had not only occupied many reflecting minds, but had been formally broached by one of them before the 'Origin of Species' appeared.

With the mass of materials furnished by the physicist and physiologist in his hands, Mr. Herbert Spencer, twenty years ago, sought to graft upon this basis a system of psychology; and two years ago a second and greatly amplified edition of his work appeared. Those who have occupied themselves with the beautiful experiments of Plateau will remember that when two spherules of olive-oil, suspended in a mixture of alcohol and water of the same density as the oil, are brought together, they do not immediately unite. Something like a pellicle appears to be formed around the drops, the rupture of which is immediately followed by the coalescence of the globules into one. There are organisms whose vital actions are almost as purely physical as that of these drops of oil. They come into contact and fuse themselves thus together. From such organisms to others a shade higher, from these to others a shade higher still, and on through an ever ascending series, Mr. Spencer conducts his argument. There are two obvious factors to be here taken into account—the creature and the medium in which it lives, or, as it is often expressed, the organism and its environment. Mr. Spencer's fundamental principle is, that between these two factors there is incessant interaction. The organism is played upon by the environment, and is modified to meet the requirements of the environment. Life he defines to be 'a continuous adjustment of internal relations to external relations.'

In the lowest organisms we have a kind of tactual sense diffused over the entire body; then, through impressions from without and their corresponding adjustments, special portions of the surface become more responsive to stimuli than others. The senses are nascent, the basis of all of them being that simple tactual sense which the sage Democritus recognised 2,300 years ago as their common progenitor. The action of light, in the first instance, appears to be a mere disturbance of the chemical processes in the animal organism, similar to that which occurs in the leaves of plants. By degrees the action becomes localised in a few pigment-cells, more sensitive to light than the surrounding tissue. The eye is incipient. At first it is merely capable of revealing differences of light and shade produced by bodies close at hand. Followed, as the interception of the light is, in almost all cases, by the contact of the closely adjacent opaque body, sight in this condition becomes a kind of 'anticipatory touch.' The adjustment continues; a slight bulging out of the epidermis over the pigment-granules supervenes. A lens is incipient, and, through the operation of infinite adjustments, at length reaches the perfection that it displays in the hawk and eagle. So of the other senses; they are special differentiations of a tissue which was originally vaguely sensitive all over.

With the development of the senses, the adjustments between the organism and its environment gradually extend in *space*, a multiplication of experiences and a corresponding modification of conduct being the result. The adjustments also extend in *time*, covering continually greater intervals. Along with this extension in space and time the adjustments also increase in speciality and complexity, passing through the various grades of brute life, and prolonging themselves into the domain of reason.

Very striking are Mr. Spencer's remarks regarding the influence of the sense of touch upon the development of intelligence. This is, so to say, the mother-tongue of all the senses, into which they must be translated to be of service to the organism. Hence its importance. The parrot is the most intelligent of birds, and its tactual power is also greatest. From this sense it gets knowledge, unattainable by birds which cannot employ their feet as hands. The elephant is the most sagacious of quadrupeds—its tactual range and skill, and the consequent multiplication of experiences, which it owes to its wonderfully adaptable trunk, being the basis of its sagacity. Feline animals, for a similar cause, are more sagacious than hoofed animals, —atonement being to some extent made in the case of the horse, by the possession of sensitive prehensile lips. In the *Primates* the evolution of intellect and the evolution of tactual appendages go hand in hand. In the most intelligent anthropoid apes we find the tactual range and delicacy greatly augmented, new avenues of knowledge being thus opened to the animal. Man crowns the edifice here, not only in virtue of his own manipulatory power, but through the enormous extension of his range of experience, by the invention of instruments of precision, which serve as supplemental senses and supplemental limbs. The reciprocal action of these is finely described and illustrated. That chastened intellectual emotion to which I have referred in connection with Mr. Darwin, is not absent in Mr. Spencer. His illustrations possess at times exceeding vividness and force; and from his style on such occasions it is to be inferred, that the ganglia of this Apostle of the Understanding are sometimes the seat of a nascent poetic thrill.

It is a fact of supreme importance that actions, the performance of which at first requires even painful effort and deliberation, may, by habit, be rendered automatic.

Witness the slow learning of its letters by a child, and the subsequent facility of reading in a man, when each group of letters which forms a word is instantly, and without effort, fused to a single perception. Instance the billiard player, whose muscles of hand and eye, when he reaches the perfection of his art, are unconsciously co-ordinated. Instance the musician, who, by practice, is enabled to fuse a multitude of arrangements, auditory, tactual, and muscular, into a process of automatic manipulation. Combining such facts with the doctrine of hereditary transmission, we reach a theory of Instinct. A chick, after coming out of the egg, balances itself correctly, runs about, picks up food, thus showing that it possesses a power of directing its movements to definite ends. How did the chick learn this very complex co-ordination of eye, muscles, and beak? It has not been individually taught; its personal experience is *nil*; but it has the benefit of ancestral experience. In its inherited organisation are registered the powers which it displays at birth. So also as regards the instinct of the hive-bee, already referred to. The distance at which the insects stand apart when they sweep their hemispheres and build their cells is 'organically remembered.' Man also carries with him the physical texture of his ancestry, as well as the inherited intellect bound up with it. The defects of intelligence during infancy and youth are probably less due to a lack of individual experience, than to the fact that in early life the cerebral organisation is still incomplete. The period necessary for completion varies with the race, and with the individual. As a round shot outstrips a rifled bolt on quitting the muzzle of the gun, so the lower race, in childhood, may outstrip the higher. But the higher eventually overtakes the lower, and surpasses it in range. As regards individuals, we do not always find the precocity of youth prolonged to mental power in maturity; while the dulness of boyhood is sometimes strikingly contrasted with the intellectual energy of after years. Newton, when a boy, was weakly, and he showed no particular aptitude at school; but in his eighteenth year he went to Cambridge, and soon afterwards astonished his teachers by his power of dealing with geometrical problems. During his quiet youth, his brain was slowly preparing itself to be the organ of those energies which he subsequently displayed.

By myriad blows (to use a Lucretian phrase) the image and superscription of the external world are stamped as states of consciousness upon the organism, the depth of the impression depending upon the number of the blows. When two or more phenomena occur in the environment invariably together, they are stamped to the same depth or to the same relief, and indissolubly connected. And here we come to the threshold of a great question. Seeing that he could in no way rid himself of the consciousness of Space and Time, Kant assumed them to be necessary 'forms of intuition,' the moulds and shapes into which our intuitions are thrown, belonging to ourselves, and without objective existence. With unexpected power and success Mr. Spencer brings the hereditary experience theory, as he holds it, to bear upon this question. 'If there exist certain external relations which are experienced by all organisms at all instants of their waking lives—relations which are absolutely constant and universal—there will be established answering internal relations, that are absolutely constant and universal. Such relations we have in those of Space and Time. As the substratum of all other relations of the Non-Ego, they must be responded to by conceptions that are the substrata of all other relations in the Ego. Being the constant and infinitely repeated elements of thought, they must become the automatic elements of thought—the elements of thought which it is impossible to get rid of—the "forms of intuition."'

Throughout this application and extension of Hartley's and Mill's 'Law of Inseparable Association,' Mr. Spencer stands upon his own ground, invoking, instead of the experiences of the individual, the registered experiences of the race. His overthrow of the restriction of experience to the individual is, I think, complete. That restriction ignores the power of organising experience, furnished at the outset to each individual; it ignores the different degrees of this power possessed by different races, and by different individuals of the same race. Were there not in the human brain a potency antecedent to all experience, a dog or a cat ought to be as capable of education as a man. These predetermined internal relations are independent of the experiences of the individual. The human brain is the 'organised register of infinitely numerous experiences received during the evolution of life, or rather during the evolution of that series of organisms through which the human organism has been reached. The effects of the most uniform and frequent of these experiences have been successively bequeathed, principal and interest, and have slowly mounted to that high intelligence which lies latent in the brain of the infant. Thus it happens that the European inherits from twenty to thirty cubic inches more of brain than the Papuan. Thus it happens that faculties, as of music, which scarcely exist in some inferior races, become congenital in superior ones. Thus it happens that out of savages unable to count up to the number of their fingers, and speaking a language containing only nouns and verbs, arise at length our Newtons and Shakspeares.'

At the outset of this Address it was stated that physical theories which lie beyond experience are derived by a process of abstraction from experience. It is instructive to note from this point of view the successive introduction of new conceptions. The idea of the attraction of gravitation was preceded by the observation of the attraction of iron by a magnet, and of light bodies by rubbed amber. The polarity of magnetism and electricity also appealed to the senses. It thus became the substratum of the conception that atoms and molecules are endowed with attractive and repellent poles, by the play of which definite forms of crystalline architecture are produced. Thus molecular force becomes *structural*.[1] It required no great boldness of thought to extend its play into organic nature, and to recognise in molecular force the agency by which both plants and animals are built up. In this way, out of experience arise conceptions which are wholly ultra-experiential. None of the atomists of antiquity had any notion of this play of molecular polar force, but they had experience of gravity as manifested by falling bodies. Abstracting from this, they permitted their atoms to fall eternally through empty space. Democritus assumed that the larger atoms moved more rapidly than the smaller ones, which they therefore could overtake, and with which they could combine. Epicurus, holding that empty space could offer no resistance to motion, ascribed to all the atoms the same velocity; but he seems to have overlooked the consequence that under such circumstances the atoms could never combine. Lucretius cut the knot by quitting the domain of physics altogether, and causing the atoms to move together by a kind of volition.

Was the instinct utterly at fault which caused Lucretius thus to swerve from his own principles? Diminishing gradually the number of progenitors, Mr. Darwin comes at length to one 'primordial form;' but he does not say, so far as I remember, how he supposes this form to have been introduced. He quotes with satisfaction the words of a celebrated author and divine who had 'gradually learnt to see that it was just as noble a conception of the Deity to believe He created a few original forms, capable of self-development into other and needful forms, as to believe He required a fresh act of creation to supply the voids caused by the action of His laws.' What Mr. Darwin thinks of this view of the introduction of life I do not know. But the anthropomorphism, which it seemed his object to set aside, is as firmly associated with the creation of a few forms as with the creation of a multitude. We need clearness and thoroughness here. Two courses and two only are possible. Either let us open our doors freely to the conception of creative acts, or, abandoning them, let us radically change our notions of Matter. If we look at matter as pictured by Democritus, and as defined for generations in our scientific text-books, the notion of conscious life coming out of it, cannot be formed by the mind. The argument placed in the mouth of Bishop Butler suffices, in my opinion, to crush all such materialism as this. Those, however, who framed these definitions of matter were but partial students. They were not biologists, but mathematicians, whose labours referred only to such accidents and properties of matter as could be expressed in their formulæ. Their science was mechanical science, not the science of life. With matter in its wholeness they never dealt; and, denuded by their imperfect definitions, 'the gentle mother of all' became the object of her children's dread. Let us reverently, but honestly, look the question in the face. Divorced from matter, where is life? Whatever our *faith* may say, our *knowledge* shows them to be indissolubly joined. Every meal we eat, and every cup we drink, illustrates the mysterious control of Mind by Matter.

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[1] See Art. VIII., Part II., of this volume, or 'Lectures on Light,' III.

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that evidence considered perfectly conclusive by many has been adduced; and that were some of us who have pondered this question to follow a very common example, and accept testimony because it falls in with our belief, we also should eagerly close with the evidence referred to. But there is in the true man of science a desire stronger than the wish to have his beliefs upheld; namely, the desire to have them true. And this stronger wish causes him to reject the most plausible support, if he has reason to suspect that it is vitiated by error. Those to whom I refer as having studied this question, believing the evidence offered in favour of 'spontaneous generation' to be thus vitiated, cannot accept it. They know full well that the chemist now prepares from inorganic matter a vast array of substances, which were some time ago regarded as the sole products of vitality. They are intimately acquainted with the structural power of matter, as evidenced in the phenomena of crystallisation. They can justify scientifically their *belief* in its potency, under the proper conditions, to produce organisms. But, in reply to your question, they will frankly admit their inability to point to any satisfactory experimental proof that life can be developed, save from demonstrable antecedent life. As already indicated, they draw the line from the highest organisms through lower ones down to the lowest, and it is the prolongation of this line by the intellect, beyond the range of the senses, that leads them to the conclusion which Bruno so boldly enunciated.[1]

The 'materialism' here professed may be vastly different from what you suppose, and I therefore crave your gracious patience to the end. 'The question of an external world,' says J. S. Mill, 'is the great battleground of metaphysics.'[2] Mr. Mill himself reduces external phenomena to 'possibilities of sensation.' Kant, as we have seen, made time and space 'forms' of our own intuitions. Fichte, having first by the inexorable logic of his understanding proved himself to be a mere link in that chain of eternal causation which holds so rigidly in nature, violently broke the chain by making nature, and all that it inherits, an apparition of the mind.[1] And it is by no means easy to combat such notions. For when I say I see you, and that I have not the least doubt about it, the obvious reply is, that what I am really conscious of is an affection of my own retina. And if I urge that I can check my sight of you by touching you, the retort would be that I am equally transgressing the limits of fact; for what I am really conscious of is, not that you are there, but that the nerves of my hand have undergone a change. All we hear, and see, and touch, and taste, and smell, are, it would be urged, mere variations of our own condition, beyond which, even to the extent of a hair's breadth, we cannot go. That anything answering to our impressions exists outside of ourselves is not a *fact*, but an *inference*, to which all validity would be denied by an idealist like Berkeley, or by a sceptic like Hume. Mr. Spencer takes another line. With him, as with the uneducated man, there is no doubt or question as to the existence of an external world. But he differs from the uneducated, who think that the world really *is* what consciousness represents it to be. Our states of consciousness are mere *symbols* of an outside entity which produces them and determines the order of their succession, but the real nature of which we can never know.[2] In fact, the whole process of evolution is the manifestation of a Power absolutely inscrutable to the intellect of man. As little in our day as in the days of Job can man by searching find this Power out. Considered fundamentally, then, it is by the operation of an insoluble mystery that life on earth is evolved, species differentiated, and mind unfolded from their prepotent elements in the immeasurable past. There is, you will observe, no very rank materialism here.

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[1] Bruno was a 'Pantheist,' not an 'Atheist' or a 'Materialist.'

[2] 'Examination of Hamilton,' p. 154.

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[1] 'Bestimmung des Menschen.

[2] In a paper, at once popular and profound, entitled 'Recent Progress in the Theory of Vision,' contained in the volume of lectures by Helmholtz, published by Longmans, this symbolism of our states of consciousness is also dwelt upon. The impressions of sense are the mere *signs* of external

The strength of the doctrine of evolution consists, not in an experimental demonstration (for the subject is hardly accessible to this mode of proof), but in its general harmony with scientific thought. From contrast, moreover, it derives enormous relative strength. On the one side we have a theory (if it could with any propriety be so called) derived, as were the theories referred to at the beginning of this Address, not from the study of nature, but from the observation of men—a theory which converts the Power whose garment is seen in the visible universe into an Artificer, fashioned after the human model, and acting by broken efforts as man is seen to act. On the other side we have the conception that all we see around us, and all we feel within us—the phenomena of physical nature as well as those of the human mind—have their unsearchable roots in a cosmical life, if I dare apply the term, an infinitesimal span of which is offered to the investigation of man. And even this span is only knowable

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things. In this paper Helmholtz contends strongly against the view that the consciousness of space is inborn; and he evidently doubts the power of the chick to pick up grains of corn without preliminary lessons. On this point, he says, further experiments are needed. Such experiments have been since made by Mr. Spalding, aided, I believe, in some of his observations by the accomplished and deeply lamented Lady Amberly; and they seem to prove conclusively that the chick does not need a single moment's tuition to enable it to stand, run, govern the muscles of its eyes, and peck. Helmholtz, however, is contending against the notion of pre-established harmony; and I am not aware of his views as to the organisation of experiences of race or breed.

in part. We can trace the development of a nervous system, and correlate with it the parallel phenomena of sensation and thought. We see with undoubting certainty that they go hand in hand. But we try to soar in a vacuum the moment we seek to comprehend the connection between them. An Archimedean fulcrum is here required which the human mind cannot command; and the effort to solve the problem—to borrow a comparison from an illustrious friend of mine—is like the effort of a man trying to lift himself by his own waistband. All that has been said in this discourse is to be taken in connection with this fundamental truth. When 'nascent senses' are spoken of, when 'the differentiation of a tissue at first vaguely sensitive all over' is spoken of, and when these processes are associated with 'the modification of an organism by its environment,' the same parallelism, without contact, or even approach to contact, is implied. Man the *object* is separated by an impassable gulf from man the *subject*. There is no motor energy in the human intellect to carry it, without logical rupture, from the one to the other.

Further, the doctrine of evolution derives man, in his totality, from the interaction of organism and environment through countless ages past. The Human Understanding, for example,—that faculty which Mr. Spencer has turned so skilfully round upon its own antecedents—is itself a result of the play between organism and environment through cosmic ranges of time. Never, surely, did prescription plead so irresistible a claim. But then it comes to pass that, over and above his understanding, there are many other things appertaining to man, whose prescriptive rights are quite as strong as those of the understanding itself. It is a result, for example, of the play of organism and environment that sugar is sweet, and that aloes are bitter; that the smell of henbane differs from the perfume of a rose. Such facts of consciousness (for which, by the way, no adequate reason has ever been rendered) are quite as old as the understanding; and many other things can boast an equally ancient origin. Mr. Spencer at one place refers to that most powerful of passions—the amatory passion—as one which, when it first occurs, is antecedent to all relative experience whatever; and we may pass its claim as being at least as ancient, and as valid, as that of the understanding itself. Then there are such things woven into the texture of man as the feeling of Awe, Reverence, Wonder—and not alone the sexual love just referred to, but the love of the beautiful, physical, and moral, in Nature, Poetry, and Art. There is also that deep-set feeling, which, since the earliest dawn of history, and probably for ages prior to all history, incorporated itself in the Religions of the world. You, who have escaped from these religions into the high-and-dry light of the intellect, may deride them; but in so doing you deride accidents of form merely, and fail to touch the immovable basis of the religious sentiment in the nature of man. To yield this sentiment reasonable satisfaction is the problem of problems at the present hour. And grotesque in relation to scientific culture as many of the religions of the world have been and are—dangerous, nay, destructive, to the dearest privileges of freemen as some of them undoubtedly have been, and would, if they could, be again—it will be wise to recognise them as the forms of a force, mischievous if permitted to intrude on the region of objective *knowledge*, over which it holds no command, but capable of adding, in the region of *poetry* and *emotion*, inward completeness and dignity to man.

Feeling, I say again, dates from as old an origin and as high a source as intelligence, and it equally demands its range of play. The wise teacher of humanity will recognise the necessity of meeting this demand, rather than

an-of resisting it on account of errors and absurdities of form. What we should resist, at all hazards, is the attempt made in the past, and now repeated, to found upon this elemental bias of man's nature a system which should exercise despotic sway over his intellect. I have no fear of such a consummation. Science has already to some extent leavened the world: it will leaven it more and more; and I should look upon the mild light of science breaking in upon the minds of the youth of Ireland, and strengthening gradually to the perfect day, as a surer check to any intellectual or spiritual tyranny which now threatens this island, than the laws of princes or the swords of emperors. We fought and won our battle even in the Middle Ages: should we doubt the issue of another conflict with our broken foe?

The impregnable position of science may be described in a few words. We claim, and we shall wrest from theology, the entire domain of cosmological theory. All schemes and systems which thus infringe upon the domain of science must, *in so far as they do this*, submit to its control, and relinquish all thought of controlling it. Acting otherwise proved disastrous in the past, and it is simply fatuous to-day. Every system which would escape the fate of an organism too rigid to adjust itself to its environment, must be plastic to the extent that the growth of knowledge demands. When this truth has been thoroughly taken in, rigidity will be relaxed, exclusiveness diminished, things now deemed essential will be dropped, and elements now rejected will be assimilated. The lifting of the life is the essential point; and as long as dogmatism, fanaticism, and intolerance are kept out, various modes of leverage may be employed to raise life to a higher level.

Science itself not unfrequently derives motive power from an ultra-scientific source. Some of its greatest discoveries have been made under the stimulus of a non-scientific ideal. This was the case among the ancients, and it has been so amongst ourselves. Mayer, Joule, and Colding, whose names are associated with the greatest of modern generalisations, were thus influenced. With his usual insight, Lange at one place remarks, that 'it is not always the objectively correct and intelligible that helps man most, or leads most quickly to the fullest and truest knowledge. As the sliding body upon the brachystochrone reaches its end sooner than by the straighter road of the inclined plane, so, through the swing of the ideal, we often arrive at the naked truth more rapidly than by the direct processes of the understanding.' Whewell speaks of enthusiasm of temper as a hindrance to science; but he means the enthusiasm of weak heads. There is a strong and resolute enthusiasm in which science finds an ally; and it is to the lowering of this fire, rather than to the diminution of intellectual insight, that the lessening productiveness of men of science, in their mature years, is to be ascribed. Mr. Buckle sought to detach intellectual achievement from moral force. He gravely erred; for without moral force to whip it into action, the achievement of the intellect would be poor indeed.

It has been said by its opponents that science divorces itself from literature; but the statement, like so many others, arises from lack of knowledge. A glance at the less technical writings of its leaders—of its Helmholtz, its Huxley, and its Du Bois-Reymond—would show what breadth of literary culture they command. Where among modern writers can you find their superiors in clearness and vigour of literary style? Science desires not isolation, but freely combines with every effort towards the bettering of man's estate. Single-handed, and supported not by outward sympathy, but by inward force, it has built at least one great wing of the many-mansioned home which man in his to-

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regards you, I thought you ought to know the environment which, with or without your consent, is rapidly surrounding you, and in relation to which some adjustment on your part may be necessary. A hint of Hamlet's, however, teaches us how the troubles of common life may be ended; and it is perfectly possible for you and me to purchase intellectual peace at the price of intellectual death. The world is not without refuges of this description; nor is it wanting in persons who seek their shelter, and try to persuade others to do the same. The unstable and the weak have yielded and will yield to this persuasion, and they to whom repose is sweeter than the truth. But I would exhort you to refuse the offered shelter, and to scorn the base repose—to accept, if the choice be forced upon you, commotion before stagnation, the breezy leap of the torrent before the fœtid stillness of the swamp. In the course of this Address I have touched on debatable questions, and led you over what will be deemed dangerous ground—and this partly with the view of telling you that, as regards these questions, science claims unrestricted right of search. It is not to the point to say that the views of Lucretius and Bruno, of Darwin and Spencer, may be wrong. Here I should agree with you, deeming it indeed certain that these views will undergo modification. But the point is, that, whether right or wrong, we claim the right to discuss them. For science, however, no exclusive claim is here made; you are not urged to erect it into an idol. The inexorable advance of man's understanding in the path of knowledge, and those unquenchable claims of his moral and emotional nature, which the understanding can never satisfy, are here equally set forth. The world embraces not only a Newton, but a Shakspeare—not only a Boyle, but a Raphael—not only a Kant, but a Beethoven—not only a Darwin, but a Carlyle. Not in each of these, but in all, is human nature whole. They are not opposed, but supplementary—not mutually exclusive, but reconcilable. And if, unsatisfied with them all, the human mind, with the yearning of a pilgrim for his distant home, will still turn to the Mystery from which it has emerged, seeking so to fashion it as to give unity to thought and faith; so long as this is done, not only without intolerance or bigotry of any kind, but with the enlightened recognition that ultimate fixity of conception is here unattainable, and that each succeeding age must be held free to fashion the mystery in accordance with its own needs—then, casting aside all the restrictions of Materialism, I would affirm this to be a field for the noblest exercise of what, in contrast with the *knowing* faculties, may be called the *creative* faculties of man. Here, however, I touch a theme too great for me to handle, but which will assuredly be handled by the loftiest minds, when you and I, like streaks of morning cloud, shall have melted into the infinite azure of the past.

Prefatory Remarks.

I.

At the request of my Publishers, strengthened by the expressed desire of many Correspondents, I reprint, with a few slight alterations, this Address.

It was written under some disadvantages this year in the Alps, and sent by instalments to the printer. When read subsequently it proved too long for its purpose, and several of its passages were accordingly struck out. Some of them are here restored.

It has provoked an unexpected amount of criticism. This, in due time, will subside; and I confidently look forward to a calmer future for a verdict, founded not on imaginary sins, but on the real facts of the case.

Of the numberless strictures and accusations, some of them exceeding fierce, of which I have been, and continue to be, the object, I refrain from speaking at any length. To one or two of them, however, out of respect for their sources, I would ask permission briefly to refer.

An evening paper of the first rank,[1] after the ascription to me of various more or less questionable aims and motives, proceeds to the imputation, that I permitted the cheers of my audience to 'stimulate' me to the utterance of words which no right-minded man, without a sense of the gravest responsibility, could employ. I trust the author of this charge will allow me in all courtesy to assure him that the words ascribed by him to the spur of the moment were written in Switzerland; that they stood in the printed copy of the Address from which I read, and were in the hands of various London editors some days previous to the reading; that they evoked no 'cheers,' but a silence far more impressive than cheers; and that, finally, as regards both approbation and the reverse, my course had been thought over, and decided, long before I ventured to address a Belfast audience.

A writer in an able theological journal represents me as 'patting religion on the back.'[2] The thought of doing so is certainly his, not mine. The facts of religious feeling are to me as certain as the facts of physics. But the world, I hold, will have to distinguish between the feeling and its forms, and to vary the latter in accordance with the intellectual condition of the age.

I am unwilling to dwell upon statements ascribed to eminent men, which may be imperfectly reported in the newspapers, and I therefore pass over a recent sermon attributed to the Bishop of Manchester with the remark, that one engaged so much as he is in busy and, I doubt not on the whole, beneficent outward life, is not likely to be among the earliest to discern the more inward and spiritual signs of the times, or to prepare for the condition which they foreshadow.

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[1] The 'Pall Mall Gazette.'

[2] The same journal was good enough to speak with approval of my address on the 'Scientific Use of the Imagination,' the 'materialism' of which is quite as pronounced as that of the 'Belfast Address.'

In a recent speech at Dewsbury, the Dean of Manchester is reported to have expressed himself thus: 'The Professor [myself] ended a most remarkable and eloquent speech by terming himself a material Atheist.' My attention was drawn to Dean Cowie's statement by a correspondent, who described it as standing 'conspicuous among the strange calumnies' with which my words have been assailed. For myself I use no language which could imply that I am hurt by such attacks. They have lost their power to wound or injure. So likewise as regards a resolution recently passed by the Presbytery of Belfast, in which Professor Huxley and myself are spoken of as 'ignoring the existence of God, and advocating pure and simple materialism;' had the possessive pronoun 'our' preceded 'God,' and had the words 'what we consider' preceded 'pure,' this statement would have been objectively true; but to make it so this qualification is required.

Cardinal Cullen, I am told, is also actively engaged in erecting spiritual barriers against the intrusion of 'Infidelity' into Ireland. His Eminence, I believe, has reason to suspect that the Catholic youth around him are not proof to the seductions of science. Strong as he is, I believe him to be impotent here. The youth of Ireland will imbibe science, however slowly; they will be leavened by it, however gradually. And to its inward modifying power among Catholics themselves, rather than to any Protestant propagandism, or other external influence, I look for the abatement of various incongruities, conspicuous among which stand those mediæval proceedings which, to the scandal and amazement of our nineteenth century intelligence, have been revived among us during the last two years.

In connection with the charge of Atheism, I would make one remark. Christian men are proved by their writings to have their hours of weakness and of doubt, as well as their hours of strength and of conviction; and men like myself share, in their own way, these variations of mood and tense. Were the religious moods of many of my assailants the only alternative ones, I do not know how strong the claims of the doctrine of 'Material Atheism' upon my allegiance might be. Probably they would be very strong. But, as it is, I have noticed during years of self-observation that it is not in hours of clearness and vigour that this doctrine commends itself to my mind; that in the presence of stronger and healthier thought it ever dissolves and disappears, as offering no solution of the mystery in which we dwell, and of which we form a part.

To coarser attacks and denunciations I pay no attention; nor have I any real reason to complain of revilings addressed to me, which professing Christians, as could readily be proved, do not scruple to use towards each other.[1] The more agreeable task remains to me of thanking those who have tried, however hopelessly, to keep accusation within the bounds of justice, and who, privately, and at some risk in public, have honoured me with the expression of their sympathy and approval.

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[1] I had some notion of comparing at this place the amenities of Christian men towards each other, with those of the Christian towards the 'infidel.' I refrain from doing so, simply because the samples before me, on both sides (I say it with deliberation), are too brutal to be repeated. Give me, for my part, a resigned and dignified atheism, rather than a theism with an outcome such as this. It would, however, be unjust to take these

JOHN TYNDALL.

ATHENÆUM CLUB:
September 15, 1874.

Prefatory Remarks.

II.

BEING AN APOLOGY FOR THE BELFAST ADDRESS.

I TAKE advantage of a pause in the issue of this Address to add a few prefatory words to those already printed.

The world has been frequently informed of late that I have raised up against myself a host of enemies; and considering, with few exceptions, the deliverances of the Press, and more particularly of the religious Press, I am forced to admit that the statement is only too true. I derive some comfort, nevertheless, from the reflection of Diogenes, transmitted to us by Plutarch, that 'he who would be saved must have good friends or violent enemies; and that he is best off who possesses both.'[1] This 'best' condition, I have reason to believe, is mine.

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critics of the baser sort as illustrations of the influence of theologic dogma. Even in this discussion liberality of thought and courtesy of language have not been wanting on the part of some of my opponents. 1875.

[1] 'Fortnightly Review,' vol. xiv. p. 636.

Reflecting on the fraction I have read of recent remonstrances, appeals, menaces, and judgments—covering not only the world that now is, but that which is to come—I have noticed with mournful interest how trivially men seem to be influenced by what they call their religion, and how potently by that 'nature' which it is the alleged province of religion to eradicate or subdue. From fair and manly argument, from the tenderest and holiest sympathy on the part of those who desire my eternal good, I pass by many gradations, through deliberate unfairness, to a spirit of bitterness which desires with a fervour inexpressible in words my eternal ill. Now, were religion the potent factor, we might expect a homogeneous utterance from those professing a common creed, while, if human nature be the really potent factor, we may expect utterances as heterogeneous as the characters of men. As a matter of fact we have the latter; suggesting to my mind that the common religion, professed and defended by these different people, is merely the accidental conduit through which they pour their own tempers, lofty or low, courteous or vulgar, mild or ferocious, as the case may be. Pure abuse, however, as serving no good end, I have, wherever possible, deliberately avoided reading, wishing, indeed, to keep, not only hatred, malice, uncharitableness, but even every trace of irritation, far away from my side of a discussion, which demands not only good temper, but largeness, clearness, and many-sidedness of mind, if it is to guide us even to provisional solutions.

At an early stage of the controversy, a distinguished Professor of the University of Cambridge was understood to argue—and his argument was caught up with amusing eagerness by a portion of the religious Press—that my ignorance of mathematics renders me incompetent to speculate on the proximate origin of life. Had I thought his argument relevant, my reply would have been simple;

for before me lies a printed document, more than twenty-two years old, bearing the signature of this same learned Professor, in which he was good enough to testify that I am 'well versed in pure mathematics.'

It has been stated, with many variations of note and comment, that in the Address as published by Messrs. Longman I have retracted opinions uttered at Belfast. A Roman Catholic writer is specially strong upon this point. Startled by the deep chorus of dissent which my dazzling fallacies have evoked, I am now trying to retreat. This he will by no means tolerate. 'It is too late now to seek to hide from the eyes of mankind one foul blot, one ghastly deformity. Professor Tyndall has himself told us how and where this Address of his was composed. It was written among the glaciers and the solitudes of the Swiss mountains. It was no hasty, hurried, crude production; its every sentence bore marks of thought and care.'

My critic intends to be severe: he is simply just. In the 'solitudes' to which he refers I worked with deliberation; endeavouring even to purify my intellect by disciplines similar to those enjoined by his own Church for the sanctification of the soul. I tried, moreover, in my ponderings to realise not only the lawful, but the expedient; and to permit no fear to act upon my mind, save that of uttering a single word on which I could not take my stand, either in this or in any other world.

Still my time was so brief, and my process of thought and expression so slow, that, in a literary point of view, I halted, not only behind the ideal, but behind the possible. Hence, after the delivery of the Address, I went over it with the desire, not to revoke its principles, but to improve it verbally, and above all to remove any word which might give colour to the notion of 'heat and haste.' In holding up as a warning to writers of the present the errors and follies of the denouncers of the past, I took occasion to compare the intellectual propagation of such denouncers to that of thistle-germs: the expression was thought offensive, and I omitted it. It is still omitted from the Address. There was also another passage, which ran thus: 'It is vain to oppose this force [of religion] with a view to its extirpation. What we should oppose, to the death if necessary, is every attempt to found upon this elemental bias of man's nature, a system which should exercise despotic sway over his intellect. I do not fear any such consummation. Science has already to some extent leavened the world, and it will leaven it more and more. I should look upon the mild light of science breaking in upon the minds of the youth of Ireland, and strengthening gradually to the perfect day, as a surer check to any intellectual or spiritual tyranny which might threaten this island, than the laws of princes or the swords of emperors. Where is the cause of fear? We fought and won our battle even in the Middle Ages; why should we doubt the issue of a conflict now?'

This passage also was deemed unnecessarily warm, and I therefore omitted it. I fear it was an act of weakness on my part to do so. For, considering the aims and acts of that renowned organisation, which for the time being wields the entire power of my critic's Church, not only resistance to its further progress, but, were it not for the intelligence of Roman Catholic laymen, positive restriction of its present power for evil, might well become the necessary attitude of society as regards that organisation. With some slight verbal alterations, therefore, which do not impair its strength, the passage has been restored.

My critic is very hard upon the avowal in my Preface regarding Atheism. But I frankly confess that his honest hardness and hostility are to me preferable to the milder but more unfair treatment which the passage has received from members of other Churches. He quotes the paragraph, and goes on to say: 'We repeat this is a most remarkable passage. Much as we dislike seasoning polemics with strong words, we assert that this Apology only tends to affix with links of steel to the name of Professor Tyndall, the dread imputation against which he struggles.'

Here we have a very fair example of subjective religious vigour. But my quarrel with such exhibitions is that they do not always represent objective fact. No atheistic reasoning can, I hold, dislodge religion from the heart of man. Logic cannot deprive us of life, and religion is life to the religious. As an experience of consciousness it is perfectly beyond the assaults of logic. But the religious life is often projected in external forms—I use the word in its widest sense—and this embodiment of the religious sentiment will have to bear more and more, as the world becomes more enlightened, the stress of scientific tests. We must be careful of projecting into external nature that which belongs to ourselves. My critic commits this mistake: he feels, and takes delight in feeling, that I am struggling, and he obviously experiences the most exquisite pleasures of 'the muscular sense' in holding me down. His feelings are as real, as if his imagination of what mine are were equally real. His picture of my 'struggles' is, however, a mere delusion. I do not struggle. I do not fear the charge of Atheism; nor should I even disavow it, in reference to any definition of the Supreme which he, or his order, would be likely to frame. His 'links' and his 'steel' and his 'dread imputations' are, therefore, even more unsubstantial than my 'streaks of morning cloud,' and they may be permitted to vanish together.

Soon after the delivery of the 'Belfast Address' the able and respected Bishop of Manchester did me the honour of noticing it; and in reference to that notice a brief and, I trust, not uncourteous remark was introduced into my first Preface. Since that time the Bishop's references to me have been very frequent. Assuredly this is to me an unexpected honour. Still a doubt may fairly be entertained whether this incessant speaking before public assemblies, on a profoundly emotional subject, does not tend to disturb that equilibrium of head and heart which it is always so desirable to preserve—whether, by giving an injurious predominance to the feelings, it does not tend to swathe the intellect in a warm haze, thus making the perception, and consequent rendering of facts, indefinite, if not untrue. It was to the Bishop I referred in a recent brief discourse as 'an able and, in many respects, a courageous man running to and fro upon the earth, and wringing his hands over the threatened loss of his ideals.' It is doubtless to this sorrowing mood—this partial and, I trust, temporary overthrow of the judgment by the emotions—that I must ascribe a probably unconscious, but still grave, misrepresentation, contained in the Bishop's last reference to me. In the 'Times' of November 9 he is reported to have expressed himself thus: 'In his lecture in Manchester Professor Tyndall as much as said that at Belfast he was not in his best mood, and that his despondency passed away in brighter moments.' Now, considering that a verbatim report of the lecture was at hand in the 'Manchester Examiner,' and that my own corrected edition of it was to be had for a penny, the Bishop, I submit, might have afforded to repeat what I actually said, instead of what I 'as much as said.' I am sorry to add that his rendering of my words is a vain imagination of his own. In my lecture at Manchester there was no reference, expressed or implied, to my moods in Belfast.

To all earnest and honest minds acquainted with the paragraph of my first Preface,[1] on which the foregoing remark of Bishop Fraser, and similar remarks of his ecclesiastical colleagues, not to mention those of less responsible persons, are founded, I leave the decision of the question, whether their mode of presenting this paragraph to the public be straightforward or the reverse.

These minor and more purely personal matters at an end, the weightier allegation remains, that at Belfast I misused my position by quitting the domain of science, and making an unjustifiable raid into the domain of theology. This I fail to see. Laying aside abuse, I hope my accusers will consent to reason with me. Is it not competent for a scientific man to speculate on the antecedents of the solar system? Did Kant, Laplace, and William Herschel quit their legitimate spheres, when they prolonged the intellectual vision beyond the boundary of experience, and propounded the nebular theory? Accepting that theory as probable, is it not permitted to a scientific man to follow up, in idea, the series of changes associated with the condensation of the nebulæ; to picture the successive detachment of planets and moons, and the relation of all of them to the sun? If I look upon our earth, with its orbital revolution and axial rotation, as one small issue of the process which made the solar system what it is, will any theologian deny my right to entertain and express this theoretic view? Time was when a multitude of theologians would be found to do so—when that arch-enemy of science which now vaunts its tolerance would have made a speedy end of the man who might venture to publish any opinion of the kind. But, that time, unless the world is caught strangely slumbering, is for ever past.

As regards inorganic nature, then, we may traverse, without let or hindrance, the whole distance which separates the nebulæ from the worlds of to-day. But only a few years ago this now conceded ground of science was theological ground. I could by no means regard this as the final and sufficient concession of theology; and, at Belfast, I thought it not only my right but my duty to state that, as regards the organic world, we must enjoy the freedom which we have already won in regard to the inorganic. I could not discern the shred of a title-deed which gave any man, or any class of men, the right to open the door of one of these worlds to the scientific searcher, and to close the other against him. And I considered it frankest, wisest, and in the long run most conducive to permanent peace, to indicate, without evasion or reserve, the ground that belongs to Science, and to which she will assuredly make good her claim.

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[1] P. 537.

Considering the freedom allowed to all manner of opinions in England, surely this was no extravagant position for me to assume. I have been reminded that an eminent predecessor of mine in the Presidential chair, expressed a totally different view of the Cause of things from that enunciated by me. In doing so he transgressed the bounds of science at least as much as I did; but nobody raised an outcry against him. The freedom he took I claim. And looking at what I must regard as the extravagances of the religious world; at the very inadequate and foolish notions concerning this universe, which are entertained by the majority of our authorised religious teachers; at the waste of energy on the part of good men over things unworthy, if I might say it without discourtesy, of the attention of enlightened heathens; the fight about the fripperies of Ritualism, and the verbal quibbles of the Athanasian Creed; the forcing on the public view of Pontigny Pilgrimages; the dating of historic epochs from the definition of the Immaculate Conception; the proclamation of the Divine Glories of the Sacred Heart—

standing in the midst of these chimeras, which astound all thinking men, it did not appear to me extravagant to claim the public tolerance for an hour and a half, for the statement of more reasonable views; views more in accordance with the verities which science has brought to light, and which many weary souls would, I thought, welcome with gratification and relief.

But to come to closer quarters. The expression to which the most violent exception has been taken is this: 'Abandoning all disguise, the confession I feel bound to make before you is, that I prolong the vision backward across the boundary of the experimental evidence, and discern in that Matter which we, in our ignorance, and notwithstanding our professed reverence for its Creator, have hitherto covered with opprobrium, the promise and potency of every form and quality of life.' To call it a 'chorus of dissent,' as my Catholic critic does, is a mild way of describing the storm of opprobrium with which this statement has been assailed. But the first blast of passion being past, I hope I may again ask my opponents to consent to reason. First of all, I am blamed for crossing the boundary of the experimental evidence. This, I reply, is the habitual action of the scientific mind—at least of that portion of it which applies itself to physical investigation. Our theories of light, heat, magnetism, and electricity, all imply the crossing of this boundary. My paper on the 'Scientific Use of the Imagination,' and my 'Lectures on Light,' illustrate this point in the amplest manner; and in the brief discourse which follows this Address I have sought, incidentally, to make clear, that in physics the experiential incessantly leads to the ultra-experiential; that out of experience there always grows something finer than mere experience, and that in their different powers of ideal extension consists, for the most part, the difference between the great and the mediocre investigator. The kingdom of science, then, cometh not by observation and experiment alone, but is completed by fixing the roots of observation and experiment in a region inaccessible to both, and in dealing with which we are forced to fall back upon the picturing power of the mind.

Passing the boundary of experience, therefore, does not, in the abstract, constitute a sufficient ground for censure. There must have been something in my particular mode of crossing it, which provoked this tremendous 'chorus of dissent.'

Let us calmly reason the point out. I hold the nebular theory as it was held by Kant, Laplace, and William Herschel, and as it is held by the best scientific intellects of to-day. According to it, our sun and planets were once diffused through space as an impalpable haze, out of which, by condensation, came the solar system. What caused the haze to condense? Loss of heat. What rounded the sun and planets? That which rounds a tear—molecular force. For æons, the immensity of which overwhelms man's conceptions, the earth was unfit to maintain what we call life. It is now covered with visible living things. They are not formed of matter different from that of the earth around them. They are, on the contrary, bone of its bone and flesh of its flesh. How were they introduced? Was life implicated in the nebulæ—as part, it may be, of a vaster and wholly Unfathomable Life; or is it the work of a Being standing outside the nebulæ, who fashioned it and vitalised it; but whose own origin and ways are equally past finding out? As far as the eye of science has hitherto ranged through nature, no intrusion of purely creative power into any series of phenomena has ever been observed. The assumption of such a power to account for special phenomena, though often made, has always proved a failure. It is opposed to the very spirit of science, and

I therefore assumed the responsibility of holding up, in contrast with it, that method of nature which it has been the vocation and triumph of science to disclose, and in the application of which we can alone hope for further light. Holding, then, that the nebulæ and the solar system, life included, stand to each other in the relation of the germ to the finished organism, I reaffirm here, not arrogantly, or defiantly, but without a shade of indistinctness, the position laid down at Belfast.

Not with the vagueness belonging to the emotions, but with the definiteness belonging to the understanding, the scientific man has to put to himself these questions regarding the introduction of life upon the earth. He will be the last to dogmatise upon the subject, for he knows best that certainty is here for the present unattainable. His refusal of the creative hypothesis is less an assertion of knowledge than a protest against the assumption of knowledge which must long, if not for ever, lie beyond us, and the claim to which is the source of perpetual confusion upon earth. With a mind open to conviction he asks his opponents to show him an authority for the belief they so strenuously and so fiercely uphold. They can do no more than point to the Book of Genesis, or some other portion of the Bible. Profoundly interesting, and indeed pathetic, to me are those attempts of the opening mind of man to appease its hunger for a Cause. But the Book of Genesis has no voice in scientific questions. To the grasp of geology, which it resisted for a time, it at length yielded like potter's clay; its authority as a system of cosmogony being discredited on all hands, by the abandonment of the obvious meaning of its writer. It is a poem, not a scientific treatise. In the former aspect it is for ever beautiful: in the latter aspect it has been, and it will continue to be, purely obstructive and hurtful. To *knowledge* its value has been negative, leading, in rougher ages than ours, to physical, and even in our own 'free' age to moral, violence.

No incident connected with the proceedings at Belfast is more instructive than the deportment of the Catholic hierarchy of Ireland; a body usually too wise to confer notoriety upon an adversary by imprudently denouncing him. The 'Times,' to which I owe nothing on the score of sympathy, but a great deal on the score of fair play, where so much has been unfair, thinks that the Irish Cardinal, Archbishops, and Bishops, in the recent manifesto, adroitly employed a weapon which I, at an unlucky moment, placed in their hands. The antecedents of their action cause me to regard it in a different light; and a brief reference to these antecedents will, I think, illuminate not only their proceedings regarding Belfast, but other doings which have been recently noised abroad.

Before me lies a document, bearing the date of November 1873, but which, after appearing for a moment, unaccountably vanished from public view. It is a Memorial addressed by Seventy of the Students and Ex-students of the Catholic University in Ireland, to the Episcopal Board of the University; and it constitutes the plainest and bravest remonstrance ever addressed by Irish laymen to their spiritual pastors and masters. It expresses the profoundest dissatisfaction with the curriculum marked out for the students of the University; setting forth the extraordinary fact that the lecture-list for the faculty of Science, published a month before they wrote, did not contain the name of a single Professor of the Physical or Natural Sciences.

The memorialists forcibly deprecate this, and dwell upon the necessity of education in science: 'The distinguishing mark of this age is its ardour for science. The natural sciences have, within the last fifty years, become the chiefest study in the world; they are in our time pursued with an activity unparalleled in the history of mankind. Scarce a year now passes without some discovery being made in these sciences which, as with the touch of the magician's wand, shivers to atoms theories formerly deemed unassailable. It is through the physical and natural sciences that the fiercest assaults are now made on our religion. No more deadly weapon is used against our faith than the facts incontestably proved by modern researches in science.'

Such statements must be the reverse of comfortable to a number of gentlemen who, trained in the philosophy of Thomas Aquinas, have been accustomed to the unquestioning submission of all other sciences to their divine science of Theology. But something more remains: 'One thing seems certain,' say the memorialsts, viz., 'that if chairs for the physical and natural sciences be not soon founded in the Catholic University, very many young men will have their faith exposed to dangers which the creation of a school of science in the University would defend them from. For our generation of Irish Catholics are writhing under the sense of their inferiority in science, and are determined that such inferiority shall not long continue; and so, if scientific training be unattainable at our University, they will seek it at Trinity, or at the Queen's Colleges, in not one of which is there a Catholic Professor of Science.'

Those who imagined the Catholic University at Kensington to be due to the spontaneous recognition, on the part of the Roman hierarchy, of the intellectual needs of the age, will derive enlightenment from this, and still more from what follows: for the most formidable threat remains. To the picture of Catholic students seceding to Trinity and the Queen's Colleges, the memorialists add this darkest stroke of all: 'They will, in the solitude of their own homes, unaided by any guiding advice, devour the works of Hæckel, Darwin, Huxley, Tyndall, and Lyell; works innocuous if studied under a professor who would point out the difference between established facts and erroneous inferences, but which are calculated to sap the faith of a solitary student, deprived of a discriminating judgment to which he could refer for a solution of his difficulties.'

In the light of the knowledge given by this courageous memorial, and of similar knowledge otherwise derived, the recent Catholic manifesto did not at all strike me as a chuckle over the mistake of a maladroit adversary, but rather as an evidence of profound uneasiness on the part of the Cardinal, the Archbishops, and the Bishops who signed it. They acted towards it, however, with their accustomed practical wisdom. As one concession to the spirit which it embodied, the Catholic University at Kensington was brought forth, apparently as the effect of spontaneous inward force, and not of outward pressure, which was rapidly becoming too formidable to be successfully opposed.

The memorialists point with bitterness to the fact, that 'the name of no Irish Catholic is known in connection with the physical and natural sciences.' But this, they ought to know, is the complaint of free and cultivated minds wherever a Priesthood exercises dominant power. Precisely the same complaint has been made with respect to the Catholics of Germany. The great national literature and scientific achievements of that country, in modern times, are almost wholly the work of Protestants. A vanishingly small fraction of it only is derived from members of the Roman Church, although the number of these in Germany is at least as great as that of the Protestants. 'The question arises,' says a writer in an able

German periodical, 'what is the cause of a phenomenon so humiliating to the Catholics? It cannot be referred to want of natural endowment due to climate (for the Protestants of Southern Germany have contributed powerfully to the creations of the German intellect), but purely to outward circumstances. And these are readily discovered in the pressure exercised for centuries by the Jesuitical system, which has crushed out of Catholics every tendency to free mental productiveness.' It is, indeed, in Catholic countries that the weight of Ultramontanism has been most severely felt. It is in such countries that the very finest spirits, who have dared, without quitting their faith, to plead for freedom or reform, have suffered extinction. The extinction, however, was more apparent than real, and Hermes, Hirscher, and Günther, though individually broken and subdued, prepared the way, in Bavaria, for the persecuted but unflinching Frohschammer, for Döllinger, and for the remarkable liberal movement of which Döllinger is the head and guide.

Though moulded for centuries to an obedience unparalleled in any other country, except Spain, the Irish intellect is beginning to show signs of independence; demanding a diet more suited to its years than the pabulum of the Middle Ages. As for the recent manifesto in which Pope, Cardinal, Archbishops, and Bishops are united in one grand anathema, its character and fate are shadowed forth by the Vision of Nebuchadnezzar recorded in the Book of Daniel. It resembles the image, whose form was terrible, but the gold, and silver, and brass, and iron of which rested upon feet of clay. And a stone smote the feet of clay; and the iron, and the brass, and the silver, and the gold, were broken in pieces together, and became like the chaff of the summer threshing-floors, and the wind carried them away.

Monsignor Capel has recently been good enough to proclaim at once the friendliness of his Church towards true science, and her right to determine what true science is. Let us dwell for a moment on the proofs of her scientific competence. When Halley's comet appeared in 1456 it was regarded as the harbinger of God's vengeance, the dispenser of war, pestilence, and famine, and by order of the Pope the church bells of Europe were rung to scare the monster away. An additional daily prayer was added to the supplications of the faithful. The comet in due time disappeared, and the faithful were comforted by the assurance that, as in previous instances relating to eclipses, droughts, and rains, so also as regards this 'nefarious' comet, victory had been vouchsafed to the Church.

Both Pythagoras and Copernicus had taught the heliocentric doctrine—that the earth revolves round the sun. In the exercise of her right to determine what true science is, the Church, in the Pontificate of Paul V., stepped in, and by the mouth of the holy Congregation of the Index, delivered, on March 5, 1616, the following decree:—

And whereas it hath also come to the knowledge of the said holy congregation that the false Pythagorean doctrine of the mobility of the earth and the immobility of the sun, entirely opposed to Holy writ, which is taught by Nicolas Copernicus, is now published abroad and received by many. In order that this opinion may not further spread, to the damage of Catholic truth, it is ordered that this and all other books teaching the like doctrine be suspended, and by this decree they are all respectively suspended, forbidden, and condemned.

But why go back to 1456 and 1616? Far be it from me to charge bygone sins upon Monsignor Capel, were it not for the practices he upholds to-day. The most applauded dogmatist and champion of the Jesuits is, I am informed, Perrone. No less than thirty editions of a work of his have been scattered abroad for the healing of the nations. His notions of physical astronomy are virtually those of 1456. He teaches boldly that 'God does not rule by universal law . . . that when God orders a given planet to stand still He does not detract from any law passed by Himself, but orders that planet to move round the sun for such and such a time, then to stand still, and then again to move, as His pleasure may be.' Jesuitism proscribed Frohschammer for questioning its favourite dogma, that every human soul was created by a direct supernatural act of God, and for asserting that man, body and soul, came from his parents. This is the system that now strives for universal power; it is from it, as Monsignor Capel graciously informs us, that we are to learn what is allowable in science, and what is not!

In the face of such facts, which might be multiplied at will, it requires extraordinary bravery of mind, or a reliance upon public ignorance almost as extraordinary, to make the claims made by Monsignor Capel for his Church.

A German author, speaking of one who has had bitter experience in this line, describes those Catholic writers who refuse to submit to the Congregation of the Index as outlawed—fair subjects for moral assassination.[1] This is very strong; and still, judging from my own small experience, not too strong. In reference to this I would ask, not without special reason, indulgence for a brief personal allusion here. It will serve a twofold object, one of which will be manifest, the other being reserved for future treatment. Sprung from a source to which the Bible was specially dear, my early training was confined almost exclusively to it. Born in Ireland, I, like my predecessors for many generations, was taught to hold my own against the Church of Rome. I had a father whose memory ought to be to me a stay, and an example of unbending rectitude and purity of life. The small stock to which he belonged were scattered with various fortunes along that eastern rim of Leinster, from Wexford upwards, to which they crossed from the Bristol Channel. My father was the poorest of them. Socially low, but mentally and morally high and independent, by his own inner energies and affinities he obtained a knowledge of history which would put mine to shame; while the whole of the controversy between Protestantism and Romanism was at his fingers' ends. At the present moment the works and characters which occupied him come, as far-off recollections, to my mind. Claude and Bossuet, Chillingworth and Nott, Tillotson, Jeremy Taylor, Challoner and Milner, Pope and McGuire, and others whom I have forgotten, or whom it is needless to name. Still this man, so charged with the ammunition of controversy, was so respected by his Catholic fellow-townsmen, that they one and all put up their shutters when he died.

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[1] See the case of Frohschammer as sketched by a friend in the Preface to 'Christenthum und die moderne Wissenschaft.' His enemies contrived to take his bread, in great part, away, but they failed to subdue him, and not even the Pope's Nuncio could prevent five hundred students of the University of Munich from signing an Address to their Professor.

With such a preceptor, and with an hereditary interest in the Papal controversy, I naturally went into it. I did not confine myself to the Protestant statement of the question, but made myself also acquainted with the arguments of the Church of Rome. I remember to this hour the interest and surprise with which I read Challoner's 'Catholic Christian Instructed;' and on the border-line between boyhood and manhood I was to be found taking part in controversies, in which the rival faiths were pitted against each other. I sometimes took the Catholic side, and gave my Protestant antagonist considerable trouble. The views of Irish Catholics became thus intimately known to me, and there was no doctrine of Protestantism which they more emphatically rejected, and the ascription of which to them they resented more warmly, than the doctrine of the Pope's personal infallibility. Yet in the face of this knowledge it was obstinately asserted and reasserted in my presence some time ago, by a Catholic priest, that the doctrine of the infallibility of the Pope had always been maintained in Ireland.[1]

But this is an episode, intended to disabuse those who, in this country or the United States, may have been misled by reckless persons, in regard to the personal points referred to. I now return to the impersonal. The course of life upon earth, as far as Science can see, has been one of amelioration—a steady advance on the whole from the lower to the higher. The continued effort of animated nature is to improve its condition and raise itself to a loftier level. In man improvement and amelioration depend largely upon the growth of conscious knowledge, by which the errors of ignorance are continually moulted, and truth is organised. It is assuredly the advance of knowledge that has given a materialistic colour to the philosophy of this age. Materialism is therefore not a thing to be mourned over, but to be honestly considered—accepted if it be wholly true, rejected if it be wholly false, wisely sifted and turned to account if it embrace a mixture of truth and error. Of late years the study of the nervous system, and its relation to thought and feeling, have profoundly occupied enquiring minds. It is our duty not to shirk—it ought rather to be our privilege to accept—the established results of such enquiries, for here assuredly our ultimate weal depends upon our loyalty to the truth. Instructed as to the control which the nervous system exercises over man's moral and intellectual nature, we shall be better prepared, not only to mend their manifold defects, but also to strengthen and purify both. Is mind degraded by this recognition of its dependence? Assuredly not. Matter, on the contrary, is raised to the level it ought to occupy, and from which timid ignorance would remove it.

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[1] On a memory which dates back to my fifteenth year, when I first read the discussion between Mr. Pope and Father McGuire, I should be inclined to rely for proof that the Catholic clergyman, in that discussion, and in the name of his Church, repudiated the doctrine of personal infallibility.

But the light is dawning, and it will become stronger as time goes on. Even the Brighton Congress affords evidence of this. From the manifold confusions of that assemblage my memory has rescued two items, which it would fain preserve: the recognition of a relation between Health and Religion, and the address of the Rev. Harry Jones. Out of the conflict of vanities his words emerge wholesome and strong, because undrugged by dogma, coming directly from the warm brain of one who knows what practical truth means, and who has faith in its vitality and inherent power of propagation. I wonder is he less effectual in his ministry than his more embroidered colleagues? It surely behoves our teachers to come to some definite understanding as to this question of health; to see how, by inattention to it, we are defrauded, negatively and positively: negatively, by the privation of that 'sweetness and light' which is the natural concomitant of good health; positively, by the insertion into life of cynicism, ill-temper, and a thousand corroding anxieties which good health would dissipate. We fear and scorn 'materialism.' But he who knew all about it, and could apply his knowledge, might become the preacher of a new gospel. Not, however, through the ecstatic moments of the individual does such knowledge come, but through the revelations of science, in connection with the history of mankind.

Why should the Roman Catholic Church call gluttony a mortal sin? Why should fasting occupy a place in the disciplines of religion? What is the meaning of Luther's advice to the young clergyman who came to him, perplexed with the difficulties of predestination and election, if it be not that, in virtue of its action upon the brain, when wisely applied, there is moral and religious virtue even in a hydro-carbon? To use the old language, food and drink are creatures of God, and have therefore a spiritual value. The air of the Alps would be augmented tenfold in purifying power if this truth were recognised. Through our neglect of the monitions of a reasonable materialism we sin and suffer daily. I might here point to the train of deadly disorders over which science has given modern society such control—disclosing the lair of the material enemy, ensuring his destruction, and thus preventing that moral squalor and hopelessness which habitually tread on the heels of epidemics in the case of the poor.

Rising to higher spheres, the visions of Swedenborg, and the ecstacy of Plotinus and Porphyry, are phases of that psychical condition, obviously connected with the nervous system and state of health, on which is based the Vedic doctrine of the absorption of the individual into the universal soul. Plotinus taught the devout how to pass into a condition of ecstasy. Porphyry complains of having been only once united to God in eighty-six years, while his master Plotinus had been so united six times in sixty years.[1] A friend who knew Wordsworth informs me that the poet, in some of his moods, was accustomed to seize hold of an external object to assure himself of his own bodily existence. No one, I should say, has had a wider experience in this field than Mr. Emerson. As states of consciousness those phenomena have an undisputed reality, and a substantial identity; but they are connected with the most heterogeneous objective conceptions. The subjective experiences are similar, because of the similarity of the underlying nervous organisations.

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[1] I recommend to the reader's particular attention Dr. Draper's important work entitled, 'History of the Conflict between Religion and Science' (Messrs. H. S. King and Co.). There, in small compass, will be found a description of the long continued struggle between Science and the Romish Church.

But for those who wish to look beyond the practical facts, there will always remain ample room for speculation. Take the argument of the Lucretian introduced in the foregoing Address at page 498. As far as I am aware, not one of my assailants has attempted to answer it. Some of them, indeed, rejoice over the ability displayed by Bishop Butler in rolling back the difficulty on his opponent; and they even imagine that it is the Bishop's own argument that is there employed. Instructed by self-knowledge, they can hardly credit me with the wish to state both sides of the question at issue; and to show by reasoning, stronger than Butler ever used, the overthrow which awaits any doctrine of materialism based upon the definitions of matter habitually received. But the raising of a new difficulty does not abolish—does not even lessen—the old one, and the argument of the Lucretian remains untouched by anything the Bishop has said or can say.

And here it may be permitted me to add a word to an important controversy now going on. In an article on 'Physics and Metaphysics,' published in the 'Saturday Review' more than fourteen years ago [1860], I ventured to state thus the old problem of the relation of physics to consciousness: 'The philosophy of the future will assuredly take more account than that of the past, of the relation of thought and feeling to physical processes; and, it may be, that the qualities of Mind will be studied through the organism, as we now study the character of Force through the affections of ordinary matter. We believe that every thought and every feeling has its definite mechanical correlative in the nervous system—that it is accompanied by a certain separation and remarshalling of the atoms of the brain.

'This latter process is purely physical; and were the faculties we now possess sufficiently strengthened, without the creation of any new faculty, it would doubtless be within the range of our augmented powers to infer from the molecular state of the brain, the character of the thought acting upon it; and, conversely, to infer from the thought, the exact corresponding molecular condition of the brain. We do not say—and this, as will be seen, is all-important—that the inference here referred to would be an *à priori* one. What we say is, that by observing, with the faculties we assume, the state of the brain, and the associated mental affections, both might be so tabulated side by side, that if one were given, a mere reference to the table would declare the other.

'Given the masses of the planets and their distances asunder, and we can infer the perturbations consequent on their mutual attractions. Given the nature of a disturbance in water, air, or aether, and from the physical properties of the medium we can infer how its particles will be affected. The mind runs along the line of thought which connects the phenomena, and from beginning to end finds no break in the chain. But when we endeavour to pass, by a similar process, from the physics of the brain to the phenomena of consciousness, we meet a problem which transcends every conceivable expansion of the powers we now possess. We may think over the subject again and again; it eludes all intellectual presentation—we stand at length face to face with the Incomprehensible.'

The discussion above referred to turns on the question: Do states of consciousness enter as links into the chain of antecedence and sequence, which give rise to bodily actions, and to other states of consciousness; or are they merely *by-products*, which are not essential to the physical processes going on in the brain? Speaking for myself, it is certain that I have no power of imagining states of consciousness, interposed between the molecules of the brain, and influencing the transference of motion among the molecules. The thought 'eludes all mental presentation;' and hence the logic seems of iron strength which claims for the brain an automatic action, uninfluenced by states of consciousness. But it is, I believe, admitted by those who hold the automaton-theory, that states of consciousness are *produced* by the marshalling of the molecules of the brain; and this production of consciousness by molecular motion is to me quite as unthinkable as the production of molecular motion by consciousness. If, therefore, unthinkability be the proper test, I must equally reject both classes of phenomena. I, however, reject neither, and thus stand in the presence of two Incomprehensibles, instead of one Incomprehensible. While accepting fearlessly the facts of materialism dwelt upon in these pages, I bow my head in the dust before that mystery of mind, which has hitherto defied its own penetrative power, and which may ultimately resolve itself into a demonstrable impossibility of self-penetration.

But the secret is an open one—the practical monitions are plain enough, which declare that on our dealings with matter depends our weal or woe, physical and moral. The state of mind which rebels against the recognition of the claims of 'materialism' is not unknown to me. I can remember a time when I regarded my body as a weed, so much more highly did I prize the conscious strength and pleasure derived from moral and religious feeling

—which, I may add, was mine without the intervention of dogma. The error was not an ignoble one, but this did not save it from the penalty attached to error. Saner knowledge taught me that the body is no weed, and that if it were treated as such it would infallibly avenge itself. Am I personally lowered by this change of front? Not so. Give me their health, and there is no spiritual experience of those earlier years—no resolve of duty, or work of mercy, no act of self-renouncement, no solemnity of thought, no joy in the life and aspects of nature—that would not still be mine; and this without the least reference or regard to any purely personal reward or punishment looming in the future.

As I close these remarks, the latest utterances of the Bishop of Peterborough reach me. I observe with regret that, notwithstanding all their 'expansiveness,' both he and his Right Rev. Brother of Manchester, appear to know almost as little of the things which belong to our peace, as that frenzied ritualist who, a day or two ago, raised the cry of 'excommunicated heretic!' against the Bishop of Natal. Happily we have amongst us our Jowetts and our Stanleys, not to mention other brave men, who see more clearly the character and magnitude of the coming struggle; and who believe undoubtingly that out of it the truths of science will emerge with healing in their wings.

And now I have to utter a 'farewell' free from bitterness to all my readers; thanking my friends for a sympathy more steadfast, I would fain believe, if less noisy, than the antipathy of my foes; and commending to these a passage from Bishop Butler, which they have either not read or failed to lay to heart. 'It seems,' saith the Bishop, 'that men would be strangely headstrong and self-willed, and disposed to exert themselves with an impetuosity which would render society insupportable, and the living in it impracticable, were it not for some acquired moderation and self-government, some aptitude and readiness in restraining themselves, and concealing their sense of things.' In temperance of language, at least, his Grace the Archbishop of Canterbury has set a good example.[1]

JOHN TYNDALL.

ATHENÆUM CLUB:
December 5, 1874.

[1] A still more remarkable illustration of absence of vituperation, associated with real scientific insight, is furnished by the sermon of the Bishop of Carlisle, reported in the 'Oxford University Herald' for November 28, 1874. To Dr. Quarry, and to a contributor in the current number of the 'British Quarterly Review,' my special acknowledgments are due. (November, 1875.)

VIII.

CRYSTALS AND MOLECULAR FORCE.

1874.

A FEW years ago I paid a visit to a large school in the country, and was asked by the principal to give a lesson to one of the classes. I agreed to do so, provided he would let me have the youngest boys in his school. To this he willingly assented: and, after casting about in my mind as to what could be said to the little fellows, I went to a village hard by and brought some sugar-candy. This was my teaching apparatus. The boys having assembled, I began by describing the way in which sugar-candy and other artificial crystals are formed, and tried to place vividly before their young minds the architectural process by which crystals are built up. They listened to me with eager interest. I examined the crystal before them, pointing out its various faces and angles; and when they found that in a certain direction it could be split into thin laminæ with shining surfaces of cleavage, their joy was at its height. They had no notion that the thing they had been crunching and sucking all their lives, embraced so many hidden points of beauty. I spent a very pleasant hour with these young philosophers; and at the end of the lesson emptied my pockets among the class, and permitted them to experiment upon the sugar-candy in the way usual to boys.

I know not whether this great assembly will deem it an impertinence on my part if I seek to instruct them, for an hour or so, on the subject chosen for my class. In doing so I run the imminent risk of being wearisome as well as impertinent; while labouring under the further disadvantage of not being able to make matters pleasant at the conclusion of the lecture, by the process adopted at the end of my lesson to the boys. The experiment, however, must be made.

We are to consider this evening some of the phenomena of Crystallisation; but in order to trace the genesis of the notions now entertained upon the subject, we have to go a long way back. In the drawing of a bow, the darting of a javelin, the throwing of a stone—in the lifting of burdens, and in personal combats, even savage man became acquainted with the operation of *force*. His first efforts were directed towards securing food and shelter; but ages of discipline, during which his power was directed against nature, against his prey, and against his fellow-man, taught him foresight. He laid by at the proper season stores of food, thus obtaining time to look about him, and to become an observer and enquirer. He discovered two things, which must have profoundly stirred his curiosity, and sent down to us the record of his discovery. He found that a kind of resin dropped from a certain tree possessed, when rubbed, the power of drawing light bodies to itself, and of causing them to cling to it; and he also found that a particular stone exerted a similar power over a particular kind of metal. I allude, of course, to electrified amber, and to the loadstone, or natural magnet, and its power to attract particles of iron. Previous experience had enabled our early enquirer to distinguish between a push and a pull. In fact, muscular efforts might be divided into pushes and pulls. Augmented experience showed him that in the case of the magnet and the amber, pulls and pushes—

attractions and repulsions—were also exerted; and, by a kind of poetic transfer, he applied to things external to himself, the conceptions derived from the exercise of his own muscular power. The magnet and the rubbed amber also pushed and pulled, or, in other words, exerted force.

In the time of the great Lord Bacon the margin of these pushes and pulls was vastly extended by Dr. Gilbert, a man probably of firmer fibre, and of finer insight, than Bacon himself. He, moreover, was one of the earliest to enter upon that career of severe experimental research, which has rendered physical science almost as stable as the system of nature which it professes to explain. Gilbert proved that a multitude of other bodies, when rubbed, exerted the power which, thousands of years previously, had been observed in amber. In this way the notion of attraction and repulsion in external nature was rendered familiar. It was a matter of experience that bodies, between which no visible link or connection existed, possessed the power of acting upon each other; and the action came to be technically called 'action at a distance.'

But out of experience in science there always grows something finer than mere experience. Experience, in fact, only furnishes the soil for plants of higher growth; and this observation of action at a distance furnished material for speculation upon the largest of problems. Bodies were observed to fall to the earth. Why should they do so? The earth was proved to revolve round the sun; and the moon to revolve round the earth. Why should they do so? What prevents them from flying straight off into space? Supposing it to be ascertained that from a part of the earth's rocky crust a firmly-fixed and tightly-stretched chain started towards the sun, we might be inclined to conclude that the earth is held in its orbit by the chain—that the sun twirls the earth around him, as a boy twirls round his head a bullet at the end of a string. But why should the chain be needed? asks the speculative mind. It is a fact of experience that bodies can attract each other at a distance, without the intervention of any chain. Why should not the sun and earth so attract each other? and why should not the fall of bodies from a height be the result of their attraction by the earth? Here then we have one of those higher thoughts of speculation, which grow out of the fruitful soil of observation. Having started with the savage, and his sensations of muscular force, we pass on to the observation of force exerted between a magnet and rubbed amber, and the bodies which they attract, rising, by an unbroken growth of ideas, to a conception of the force by which sun and planets are held together.

This idea of attraction between sun and planets had become familiar in the time of Newton. He set himself to examine the attraction; and here, as elsewhere, we find the speculative mind falling back for its materials upon experience. It had been observed, in the case of magnetic and electric bodies, that the nearer they were brought together the stronger was the force exerted between them; while, by increasing the distance, the force diminished until it became insensible. Hence the inference that the assumed pull between the earth and the sun would be influenced by their distance asunder. Guesses had been made as to the exact manner in which the force varied with the distance; but, in the case of Newton, the guess was supplemented by being brought to the severe test of experiment and calculation. Comparing the pull of the earth upon a body close to its surface, with the pull upon the moon, 240,000 miles away, Newton rigidly established the law of variation with the distance, thus placing in our hands a principle which enables us to determine the date of astronomical events in the far historic past, or in the distant future.[1]

But on his way to this great result Newton found room in his ample mind for other conceptions, some of which, indeed, constituted the necessary stepping-stones to his result. The one which here concerns us most is this: according to Newton not only does the sun attract the earth, and the earth attract the sun, *as wholes*, but every particle of the sun attracts every particle of the earth, and the reverse. His conclusion was, that the attraction of the masses was simply the sum of the attractions of their constituent particles.

This result seems so obvious that you will perhaps wonder at my dwelling upon it; but it really marks a turning point in our notions of force. You have probably heard of late of certain disturbers of the public peace named Democritus, Epicurus, and Lucretius. These men adopted, developed, and diffused the dangerous doctrine of atoms and molecules, which found its consummation in this city of Manchester at the hands of the immortal John Dalton. Now, the grand old Pagans whom I have named, and their followers, up to the time of Newton, had pictured their atoms as falling and flying through space, hitting each other, and clinging together by imaginary hooks and claws. They entirely missed the central idea that the atoms and molecules could come together, not by being fortuitously knocked against each other, but by their own mutual attractions. This is one of the great steps taken by Newton. He familiarised the world with the conception of *molecular force*.

In the case of electricity and magnetism, a double exercise of force had been observed—repulsion had been always seen to accompany attraction. Electricity and magnetism were examples of what are called *polar forces*; and in the case of magnetism, experience itself pushed the mind irresistibly beyond the bounds of experience, compelling it to conclude that the polarity of the magnet was resident in its molecules. I hold a strip of steel by its centre, between my finger and thumb. One half of the strip attracts, and the other half repels, the north end of a magnetic needle. I break the strip in the middle, and what occurs? The middle point or equator of the magnet has shifted to the centre of the new strip. This half, which a moment ago attracted throughout its entire length the north pole of a magnetic needle, is now divided into two new halves, one of which wholly attracts, and the other of which wholly repels, the north pole of the needle. Thus the half, when broken off, proves to be as perfect a magnet as the whole. You may break this half, and go on till further breaking becomes impossible through the very smallness of the fragments; still you find at the end that the smallest fragment is endowed with two poles, and is, therefore, a perfect magnet. But you cannot stop here: you *imagine* where you cannot *experiment*; and reach the conclusion entertained by all scientific men, that the magnet which you can see and feel is an assemblage of molecular magnets which you cannot see and feel, but which must be intellectually discerned.

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[1] See pp. 396, 397, 398.

In this power of ideal extension consists for the most part the difference between great and mediocre investigators. The man who cannot break the bounds of experience, but holds on to the region of sensible facts, may be an excellent observer, but he is no philosopher, and can never reach those principles which render the facts of science organic. True, the speculative faculty may be abused like all good things, but it is not men of science that are most likely to abuse it. When, more than thirty years ago, a townsman of your own accounted for the heat of chemical combination by referring it to the clash of atoms *falling* together, he described an image presented to his mind, but entirely beyond the reach of his senses. It was, however, an image out of which grew memorable consequences; among others this one of a personal nature. The walls of this Free Trade Hall, or rather its predecessor, have rung with the speeches of Cobden, and Bright, and Wilson. But at the time when their words rolled round the world, the enquirer to whom I have referred was silently and studiously engaged in your city, grappling with the problem of heat and work, and by implication with far higher problems. He grappled with it successfully, bringing it into the full light of experimental demonstration. And I venture to affirm that in the coming time, not even the great orators and politicians just named, not even the greatest of your manufacturing princes, will enjoy a purer, a more permanent or enviable fame—there is not a man amongst them of whom Manchester will be more justly proud, than of James Prescott Joule, her modest brewer, but renowned scientific worker.

We have now to track still further the growth of our notions of force. We have learned that magnetism is a polar force; and experience hints that a force of this kind may exert a certain structural power. It is known, for example, that iron filings strewn round a magnet arrange themselves in definite lines, called, by some, 'magnetic curves,' and, by Faraday, 'lines of magnetic force.' In these observed results of magnetic polarity we find the material for speculation, in an apparently distant field. You can readily make an experiment or two for yourselves with any magnet. Over two magnets now before me, is spread a sheet of paper. Scattering iron filings over the paper, and tapping it, the filings arrange themselves in a singular manner. Polar force is here in action, and every particle of the iron responds to that force. The consequence is a certain structural arrangement, a kind of architectural effort—if I may use the term—on the part of the iron filings. Here is a fact of experience which, as you will see immediately, furnishes further material for the mind to operate upon, rendering it possible to attain intellectual clearness and repose, while speculating upon apparently remote phenomena.

You cannot enter a quarry and scrutinise the texture of the rocks without seeing that it is not perfectly homogeneous. If the quarry be of granite, you find the rocks to be an agglomeration of crystals of quartz, mica, and felspar. If the rocks be sedimentary, you find them, for the most part, composed of crystalline particles derived from older rocks. If the quarry be marble, you find the fracture of the rocks to be what is called crystalline fracture. These crystals are, in fact, everywhere. If you break a sugar-loaf, you find the surface of fracture to be composed of small, shining, crystalline surfaces. In the fracture of cast iron you notice the same thing; and next to his great object of squeezing out the entangled gas from his molten metal, another object of your celebrated townsman, Sir Joseph Whitworth, when he subsequently kneads his masses of white-hot steel, as if they were so much dough, is to abolish this crystalline structure. The shining surfaces observed in the case of crystalline fracture are surfaces of weak cohesion; and when you come to examine large and well-developed crystals, you soon learn why they are so. With the edge of my knife I try, in various directions, the crystal of sugar, referred to at the beginning of this lecture, and find it obdurate; but I at length come upon a direction in which it splits cleanly before the knife, revealing two shining surfaces of cleavage. Such surfaces are seen when you break cast iron, and the metal is strengthened by their abolition. Other crystals split far more easily than sugar.

In the course of scientific investigation, then, as I have tried to impress upon you, we make continual incursions from a physical world, where we observe facts, into a super- or sub-physical world, where the facts elude all observation, and we are thrown back upon the picturing power of the mind. By the agreement or disagreement of our picture with subsequent observation it must stand or fall. If it represent a reality, it abides with us; if not, it fades like an unfixed photograph in the presence of subsequent light. Let me illustrate this. You know how very easy it is to cleave slate rock. You know that Snowdon, Honister Crag, and other hills of Wales and Cumberland, may be thus cloven from crown to base. How was the cleavage produced? By simple bedding or stratification, you may answer. But the answer would not be correct; for, as Henslow and Sedgwick showed, the cleavage often cuts the bedding at a high angle. Well, here, as in other cases, the mind, endeavouring to find a cause, passed from the world of fact to the world of imagination, and it was assumed that slaty cleavage, like crystalline cleavage, was produced by polar force. And, indeed, an interesting experiment of Mr. Justice Grove could be called upon to support this view. I have here, in a cylinder with glass ends, a fine magnetic mud, consisting of small particles of oxide of iron suspended in water. You can render those suspended particles polar by sending round the cylinder an electric current; and one striking consequence of this action may be rendered evident. At present the particles are promiscuously strewn in the liquid, and the strongest beam of light can hardly struggle through the turbid medium. But when the current passes they all set their lengths parallel to the axis of the cylinder, and light immediately flashes out upon the screen. Now, if you imagine the mud of slate rocks to have been thus acted on, so as to place its particles with their lengths in a common direction, such elongated and flat particles would, when solidified, certainly produce a cleavage.

Here we have a sample of the 'fading photograph'; for, plausible as this is, it is not the proper explanation, the cleavage of the slate rocks being demonstrably not crystalline, but, as shown by Sharpe, Sorby, Haughton, and myself, due to pressure.

The outward forms of crystals are various and beautiful. A quartz-crystal, for example, is a six-sided prism, capped at each end by six-sided pyramids. Rock-salt, with which your neighbours in Cheshire are so well acquainted, crystallises in cubes; and it can be cloven into cubes until you cease to be able to cleave further for the very smallness of the masses. Rock-salt is thus proved to have three planes of cleavage, at right angles to each other. Iceland spar has also three planes of cleavage, but they are oblique instead of rectangular, the crystal being, therefore, a rhomb instead of a cube. Various crystals, moreover, cleave with different facilities in different directions. A plane of 'principal cleavage' exists in these crystals, and it is accompanied by other planes, sometimes of equal, sometimes of unequal, value as regards ease of cleavage. Heavy spar, for example, cleaves into prisms, with a rhombus or diamond-shaped figure for a base. It cleaves with greatest ease across the axis of the prism, the other two cleavages having equal values. Selenite cleaves with extreme facility in one direction, and with unequal facilities in two other directions.

Looking at these beautiful edifices and their internal structure, the pondering mind has forced upon it the question, How have these crystals been built up? What is the origin of this crystalline architecture? Without crossing the boundary of experience, we can make no attempt to answer this question. We have obtained clear conceptions of polar force: we know that polar force may be resident in the molecules, or smallest particles of matter, and that by the play of this force structural arrangement is possible. What, in relation to our present question, is the natural action of a mind furnished with this knowledge? Why, it is compelled by its bias towards unity of principle to transcend experience, and endow the atoms and molecules of which these crystals are built with definite poles, whence issue attractions and repulsions for other poles. In virtue of these attractions and repulsions some poles are drawn together, some retreat from each other; atom is thus added to atom, and molecule to molecule, not boisterously or fortuitously, but silently and symmetrically, and in accordance with laws more rigid than those which guide a human builder when he places his bricks and stones together. From this play of invisible particles we see finally growing up before our eyes these exquisite structures, to which we give the name of *crystals.*

In the specimens hitherto placed before you the work of the atomic architect has been completed; but you shall see him immediately at work. In the first place, however, I will try to pull to pieces before your eyes one of his most familiar edifices, ordinary ice. The agent to be employed in taking down the molecules of the ice is a suitably concentrated beam of heat. Sent skilfully through the crystal, the beam selects certain points for attack; round about those points it works silently, undoing the crystalline architecture, and reducing to the freedom of liquidity molecules which had been previously locked in a solid embrace. The liquefied spaces are rendered visible by strong illumination. Round numerous points in the ice we see expanding liquid flowers, each with six petals, and a central vacuous spot. They grow larger and larger, assuming, as they do so, beautifully crimped borders; and showing, if I might use such terms, the pains, and skill, and exquisite sense of the beautiful, displayed by nature in the formation of a common block of ice.

Here we have before us a process of demolition, which clearly reveals the reverse process of erection. I wish, however, to show you the molecules in the act of following their architectural instincts, and building themselves together. You know how alum, and nitre, and sugar crystals are formed. The substance to be crystallised is dissolved in a liquid, and the liquid is permitted to evaporate. The solution soon becomes supersaturated, for none of the solid is carried away by evaporation; and then the molecules, no longer able to enjoy the freedom of liquidity, close up together and form crystals. My object now is to make this process rapid enough to enable you to see it, and still not too rapid to be followed by the eye. For this purpose a powerful solar microscope and an intense source of light are needed. They are both here. Pouring over a clean plate of glass a solution of sal-ammoniac, and placing the glass on its edge, the excess of the liquid flows away, but a film clings to the glass. The beam employed to illuminate this film hastens its evaporation, and brings it rapidly into a state of supersaturation; and now you see the orderly progress of the crystallisation over the entire screen. You may produce something similar to this if you breathe upon the frost ferns which overspread your window-panes in winter, and permit the liquid to recrystallise. It runs, as if alive, into the most beautiful forms.

In this case the crystallising force is hampered by the adhesion of the liquid to the glass; nevertheless the play of power is strikingly beautiful. In the next example our crystals will not be so much troubled by adhesion, for we shall liberate the atoms at a distance from the surface of the glass. Sending an electric current through water, we decompose the liquid, and the bubbles of the constituent gases rise before your eyes. Sending the same current through a solution of acetate of lead, the lead is liberated, and its free atoms build themselves into crystals of marvellous beauty. They grow before you like sprouting ferns, exhibiting forms as wonderful as if they had been produced by the play of vitality itself. Nitrate of silver, thus decomposed, produces silver trees of extraordinary beauty. The *mechanism* of the process is rendered intelligible by the picture of atomic poles; but there is something here incipient, which the mind of man has never yet seized; and which, so far as research has penetrated, is found indissolubly joined with what we despise as matter. I have seen these things hundreds of times, but never without wonder. And perhaps you would allow me a moment's diversion from my subject, to say that often in the spring-time, when looking with delight on the sprouting foliage, 'considering' the lilies of the field, and sharing the general joy of opening life, I have asked myself whether there is no power, being, or thing, in the universe, whose knowledge of that of which I am so ignorant is greater than mine. I have said to myself, Can man's knowledge be the greatest knowledge—and man's life the highest life?[1] My friends, the profession of that Atheism with which I am sometimes so lightly charged would, in my case, be an impossible answer to this question: only slightly preferable to that fierce and distorted Theism which still reigns rampant in some minds, as the survival of a more ferocious age.

In the formation of our lead and silver trees, we needed an agent to wrest the lead and the silver from the acids with which they were combined. A similar agent is required in the vegetable world. The solid matter of our metallic trees was, in the first instance, disguised in a transparent liquid; the solid matter of our woods and forests is also, for the most part, disguised in a transparent gas, formed by the union of carbon and oxygen, and diffused in small quantities in the atmosphere. Subjected to an action somewhat analogous to that of the electric current, in the case of our lead and silver solutions, this gas has its carbon liberated and deposited as woody fibre. The aqueous vapour of the air, subjected to a similar action, has its hydrogen liberated from its oxygen, the former, like the carbon, entering the tissue of the tree. But what is it in nature that plays the part of the electric current in our experiments? The light-waves of the sun. The leaves of plants absorb both the carbonic acid and the aqueous vapour of the air. In the leaves, the solar rays decompose the acid and the water, permitting the oxygen, in both cases, to escape into the air, and allowing the carbon and the. hydrogen to follow the bent of their own structural forces. And just as the molecular attractions of the silver and the lead found expression in the production of those beautiful branching forms, seen in our experiments, so do the molecular attractions of the liberated carbon and hydrogen find expression in the architecture of grasses, plants, and trees.

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[1] An old reflection of mine, see p. 458.

In the fall of a cataract and in the rush of the wind we have examples of mechanical power. In the combinations of chemistry, and in the formation of crystals and vegetables, we have examples of molecular power, which may be turned to mechanical account. As regards our store of the latter, the world may be divided into two kinds of matter; or rather the matter of the world may be classified under two distinct heads—namely, atoms and molecules which have already rushed together and satisfied their mutual attractions, and atoms and molecules whose attractions are, as yet, unsatisfied. With regard to motive power, the working of machinery, or the performance of mechanical work generally, by means of the materials of the earth's crust, we are entirely dependent on those atoms and molecules whose attractions are as yet unsatisfied. These can produce motion, and it is this molecular motion that we utilise in our machines. We can get power out of oxygen and hydrogen, during the act of their union, but when they are combined, and when the motion consequent on their combination has been expended, no further power can be got out of them. As dynamic agents they are dead. When we examine the materials of the earth's crust, we find them consisting for the most part of substances whose atoms have already closed in chemical union—whose mutual attractions are satisfied. Granite, for instance, is a widely-diffused substance; but granite consists, in great part, of silicon, oxygen, potassium, calcium, and aluminium, whose atoms met long ago in chemical combination, and are therefore dead. Limestone is also a widely-diffused substance. It is composed of carbon, oxygen, and a metal called calcium. But the atoms of those substances closed long ago in chemical union, and are therefore eternally at rest.

In this way we might go over the whole of the materials of the earth's crust, and satisfy ourselves that though they were sources of power in ages past, and long before any being had appeared on the surface of the earth capable of turning their energies to account, they are not sources of power now. And here we might halt for a moment to remark on that tendency, so prevalent in the world, to regard everything as made for human use.

Those who entertain this notion hold, I think, an overweening opinion of their own importance in the system of nature. Flowers bloomed before men saw them, and the quantity of energy wasted before man could utilise it, is all but infinite compared with what now remains to be applied. We are truly heirs of all the ages; but, as honest men, it behoves us to know the extent of our inheritance; and, as brave ones, not to whimper, if it should prove to be less than we supposed. Inordinate claims and expectations are not necessary to the moulding of healthy, happy, and patriotic men. Not with beggarly fear, or mutinous discontent, but rather with elation of mind, ought we to accept the brotherhood affirmed by the poet, when asked the use of the beautiful rhodora—

> Why thou wert there, O rival of the rose!
> I never thought to ask, I never knew,
> But in my simple ignorance suppose
> The self-same Power that brought me here brought you.[1]

A few exceptions to the general state of union of the particles of the earth's crust—vast, in relation to us, but trivial in comparison to the total store of which they are the residue—still remain. They constitute our main sources of motive power. By far the most important of these are our beds of coal. Distance still intervenes between the atoms of carbon and those of atmospheric oxygen, across which the atoms may be urged by their mutual attractions; and we can utilise the motion thus produced. Once the carbon and the oxygen have rushed together, so as to form carbonic acid, their mutual attractions are satisfied; and, while they continue in this condition, as dynamic agents they are dead. A pound of coal produces by its combination with oxygen an amount of heat which, if mechanically applied, would raise a weight of a ton to a height of about a mile above the earth's surface. Conversely, a ton falling from the height of a mile, and striking against the earth, would generate an amount of heat equal to that developed by the combustion of a pound of coal. Consider, then, the enormous energies of our coal-fields. We dig annually from our pits about 100 millions of tons of coal, the combustion of a single pound of which, supposing it to take place in a minute, would be equivalent to the work of 300 horses. If we suppose 120 millions of horses working day and night with unimpaired strength for a year, their united energies would enable them to perform an amount of work just equivalent to the annual produce of our coal-fields. Our woods and forests are also sources of mechanical energy, because they have the power of uniting with the atmospheric oxygen. Passing from plants to animals, we find that the source of motive power just referred to is also the source of muscular power. A horse can perform work, and so can a man; but this work is at bottom the molecular work of the elements of the food and the oxygen of the air. We inhale this vital gas, and bring it into sufficiently close proximity with the carbon and the hydrogen of the food. These unite in obedience to their mutual attractions; and their motion towards each other, properly turned to account by the wonderful mechanism of the body, becomes muscular motion.

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[1] Emerson.

Wherever work is done by heat, heat disappears. The quantity of heat communicated to the boiler of a working steam-engine is greater than that obtainable from the recondensation of the steam after it has done its work; and the amount of work performed is the exact equivalent of the missing amount of heat. One fundamental thought pervades all such statements: there is one tap root from which they all spring. This is the ancient maxim that out of nothing nothing comes; that neither in the organic [illegible]d nor in the inorganic is power produced without the expenditure of other power; that neither in the plant nor in the animal is there a creation of force or motion. Trees grow, and so do men and horses; and here we have new power incessantly introduced upon the earth. But its source, as I have already stated, is the sun. For it is the sun that separates the carbon from the oxygen of the carbonic acid, and enables them to recombine. And whether they recombine in the furnace of the steam-engine, or in the animal body, the origin of their power is the same. In this sense we are all 'souls of fire and children of the sun;' but, as remarked by Helmholtz, we must be content to share our celestial pedigree with the meanest of living things.

I look to a still remoter brotherhood; but we are here upon the edge of a battlefield which I do not intend to enter to-night; from which, indeed, I have just escaped bespattered and begrimed, but without much loss of heart or hope. It only remains for me to briefly indicate the position of the opposing hosts. From the processes of crystallisation which you have just seen, you may pass by almost imperceptible gradations to the lowest vegetable organisms, and from these through higher ones up to the highest. The conflict referred to is: that whereas one class of thinkers regard the observed advance from the crystalline, through the vegetable and animal worlds, as an unbroken process of natural growth, thus grasping the world, inorganic and organic, as one vast and indissolubly connected whole; the other class suppose that the passage from the inorganic to the organic required a distinct creative act, and that to produce the different forms of organisms, both in the world of fossils and in the world of living things, separate creative acts were also needed.

Which are right and which are wrong is, I submit, a problem for reasonable and grave discussion, and not for anger and hard names. The question cannot be solved

—it cannot even be shelved—by angry abuse. Nor can it be answered by appeals to hopes and fears—to what we lose or gain, here or hereafter, by joining the one or the other side. The bribe of eternity itself, were it possible to offer it, could not prevent the human mind from closing with the truth. Scepticism is at the root of our fears. I mean that scepticism which holds that human nature, being essentially corrupt and vile, will go to ruin if the props of our conventional theology are not maintained. When I see an able, and in many respects a courageous, man, running to and fro upon the earth, and wringing his hands over the threatened loss of his ideals, I feel disposed to exhort him to cast out this scepticism; and to believe, undoubtingly, that in the mind of man we have the substratum of all ideals. We have there capacity which will as surely and infallibly respond to the utterances of a really living soul, as string responds to string when the proper note is sounded. It is the function of the teacher of humanity to call forth this resonance of the human heart. But the possibility of doing so depends not wholly and solely upon him, but upon the antecedent fact that the conditions for its appearance are already there.

Some of the points referred to in this fragment are connected with their historic antecedents in the article entitled 'The Copley Medallist for 1871.'

From the 'Times' of November 9, 1874.

In Medicine, as elsewhere, knowledge grows and consolidates through the conflict and sifting of opinions and evidences. With regard to the great class of diseases known as epidemics, which flourish through the transfer from place to place, and from person to person, of a something which continues to exist through its own powers of reproduction, physicians have long been divided in their notions. And with regard to the title of certain diseases to be ranked as epidemic, the opinions of the medical world have been equally divided. On this last question more especially, theoretic notions may be of the last importance, for they more or less determine the physician's practice, and have, therefore, a direct bearing upon the lives committed to his care.

On hardly any point of medical theory, and the practice flowing from it, has this division of opinion been more distinct than on the question of typhoid fever. The pith of the controversy is this: Can typhoid fever be generated anew? Is it produced by the decomposition and putrefaction of animal and vegetable substances, or must the matter producing it have had previous contact with an infected body? In other words, for every new case of typhoid fever may we with certainty infer a pre-existing case, of which the new one is merely the propagation or continuation; or are we entitled to conclude that organic matter, which has never been in contact with a typhoid patient, is, in virtue of its own decomposition, capable of starting the fever anew? When we consider that this pest sends 15,000 of the inhabitants of these islands yearly to the grave, and causes 150,000 to pass through its protracted miseries, the question here stated assumes the very gravest importance, because our relation to it must determine our mode of attack upon this enemy of mankind.

The position taken by Dr. Budd in reference to this question, is one which will render his name memorable in the history of medicine. In the work before us he seeks to prove that the first of the positions just laid down is the true position; that there is no such thing as the spontaneous generation of typhoid fever; that the malady is propagated, as surely as smallpox is propagated through a special virus, by contagion. He begins by developing his evidence on this head; he then fixes the principal seat of the contagious matter in the intestine; he examines the nature of the intestinal affection, the relation of typhoid fever to defective sewerage, the character of the contagious agent, the employment of disinfectants and disinfection. He discusses the so-called 'pythogenic' or putrescent theory, and winds up with some remarks on the spontaneous origin of typhoid fever. The book, from beginning to end, is one comprehensive argument, with reference to which it may be said that the facts alleged are of the most conclusive character, while the logic which binds them together is, as far as I can see, simply irresistible.

This is a question which is sure to occupy the attention of legislators as well as of physicians, and it is therefore desirable to place it in the clearest untechnical light. Dr. Budd takes his reader to the village of North Tawton, where he was himself born and brought up, and every inhabitant of which was personally known to him. In the village there was no general system of sewers. Round the cottages of those who earned their bread with their hands, and who formed the great bulk of the population, were collected various offensive matters. Each cottage, or group of three or four cottages, had a common privy, to which a simple excavation in the ground served as a cesspool. In many cases, hard by the cottage door there was not only an open privy, but a dung-heap, where pigs rooted and revelled. For a long period there was much offensive to the nose, but no fever.[1] An inquiry, conducted with the most scrupulous care, showed that for fifteen years there had been no severe outbreak of the disorder, and that for nearly ten years there had been only a single case. 'For the development of this fever,' adds Dr. Budd, 'a more specific element was needed than the swine, the dung-heaps, or the privies were able to furnish.'

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[1] This is the exper[illegible] poorer parts of Edinburgh. See p. [21. In [illegible] manifold th[illegible] has presented itself to me in Switzerland

That element at length came, and formed a starting-point from which its further progress might be securely followed. On July 11, 1839, a case of typhoid fever, doubtless imported from without, occurred in a poor and crowded dwelling, and before the end of November eighty of the inhabitants had suffered from it; a proportion about the same as that now suffering at Over Darwen. The reader will, I trust, bear strictly in mind that the question now before us is, whether typhoid fever is contagious, and he is asked to weigh the answer which facts return to this question. Two sawyers living near the stricken house at North Tawton, fell ill, and quitted the village for their own homes at Marchard, where no previous case of typhoid fever had been. In two days one of these men took to his bed, and at the end of five weeks he died. Ten days after his death, his two children were laid up with the fever. The other sawyer also took to his bed, and when at the worst a friend from a distance came to see him, and assisted to raise him in bed. On the tenth day after, this friend was seized with the fever. Before he became convalescent, two of his children were struck down, and his brother, who lived at a distance, but who came to see him, also fell a victim. Was this series of events the result of chance, or was it the work of contagion? Let us pursue the inquiry further. On August 20, a Mrs. Lee began to droop at North Tawton, and, not knowing what was impending, she visited her brother at Chaffcombe, seven miles off. She was smitten with the fever, and before she became convalescent, her sister-in-law, Mrs. Snell, who had nursed her, was attacked and died subsequently. Then came Mr. Snell, then one of the farm apprentices, then a day-labourer, then a Miss Snell, who had come to take charge of the house after Mrs. Snell's death; and, finally, a group consisting of a servant man, a servant girl, and another young person who had acted as nurse.

The case here submitted to the reader is not one of medical practice, but of common evidence, which does not even require a trained scientific mind to weigh it. Let us proceed. A boy who had been smitten at Chaffcombe went to his mother's cottage between Bow and North Tawton. Before he recovered, his mother, who had nursed him, sickened and died. Two children of the family next door were next attacked, then the sister of the boy who had carried the infection from Chaffcombe.

She, in her turn, removed to another place, and became a new focus for the propagation of the disease. Again, to lighten the list of invalids, a girl named Mary Gibbings was sent from Chaffcombe to her home at Loosebeare, four miles off. Here she lay ill for several weeks. Before she recovered, her father was seized. A farmer who lived across the road, and who visited Gibbings, was next struck down. His case was followed by others under the same roof; and the fever, spreading from this to other houses, became the centre of an epidemic which gradually extended to the whole hamlet.

At the same time, scattered over the country side, were some twenty or thirty other hamlets, in each of which were the usual manure yard, the inevitable pigsty, and the same primitive accommodation for human needs. 'The same sun shone upon all alike through month after month of the same fine, dry, autumnal weather. From the soil of all these hamlets human and other exuviæ exhaled into the air the same putrescent compounds in about equal abundance. In some of them, indeed, to speak the exact truth, these compounds, if the nose might be trusted—and in this matter there is no better witness—were much more ripe. And yet, while at Loosebeare a large proportion of the inhabitants were lying prostrate with fever, in not one out of the twenty or thirty similar hamlets was there a single case.'[1] There is no confusion of data here; no blur or indistinctness in the observer's vision, no flaw, as far as I can see, in his reasoning. He follows the morbific agent from place to place, sees it planted, developed, shedding its seeds, producing new crops; growing up where it is sown, and there only. Ashpits fail to develop it; putrescence fails to develop it; stench fails to develop it; even the open privy is powerless as long as it is kept free from the discharges of those already attacked. The case of North Tawton is typical; numerous other cases equally conclusive are adduced—among them the foul condition of the Thames in the hot weather of 1858 and 1859, when stench for the first time 'rose to the height of an historic event;' and when, nevertheless, London, even along the river, enjoyed a singular immunity from fever. It is,

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[1] With such evidence as this before me, corroborated as it is in the most diversified manner by my own experience, I cannot accept for my guidance either the knowledge or the scientific competence of some of those who have made this letter the subject of criticism.

I think, impossible for any intelligent reader, and I should say certainly impossible for any man trained to scientific reasoning, to quit Dr. Budd's volume without closing with his conclusion, that the *living human body is the soil in which the specific poison of typhoid fever breeds and multiplies.*

What is the seat of the poison? Dr. Budd is too cautious to shut out the possibility of infection by any of the emanations from a person suffering from the disease. But its special and almost exclusive *locus* is the diseased intestine. He gives drawings and photographs of the bowel at various stages of the disease; and it is hardly possible to look on these without coming to the conclusion that the whole interior surface of the bowels is the seat of an eruption. The pustules or protuberant patches, called 'Peyer's patches,' thicken and stand out in relief from the surface of the gut. They feel, to use the words of Chomel, as if a solid and elastic substance had been inserted between the coats of the intestine, while, when a patch is cut through, its texture is seen to be occupied by a yellowish-white cheese-like matter. 'This is the peculiar "typhoid matter" whose presence is typical of the disease, and whose formation and elimination constitute the essence of the intestinal process.' Louis has made careful observations as to the duration of the alvine discharge which accompanies typhoid fever, and finds it to be in mild cases 15, and in severe cases 25 days. For this period, therefore, every individual smitten at Over Darwen has been flooding the undrained ground with the poison of this contagious fever. It reaches the drinking water; it partially dries and floats in the air; it rises mechanically with the gas-bubbles issuing from cesspools, and thus the pestilence wraps like an atmosphere the entire community.

How could a disease whose characteristics are so severely demonstrable have ever been imagined to be non-contagious? How could such a doctrine be followed out, as it has been, to the destruction of human life? Mainly because practice in cities, where the greatest medical authorities reside, was directly calculated to throw the physician off the scent. The seat of the disease being the intestine, with well-appointed water-closets it is not in the sick-room that the mischief is done, but often at a distance from the sick-room, through the agency of the sewer, which Budd graphically describes as 'a direct continuation of the diseased intestine.' Hence the mystic power of 'sewer-gas. Hence the inability of the metropolitan practitioner to trace the disease to its origin. Hence the immunity of undrained country villages as long as the specific poison keeps away; and hence also the localised ravages of the disease in such villages as soon as it appears.

Were it not that I have already drawn far too heavily upon your space, I might enlarge upon these subjects. I will limit myself to one more point of commanding interest. What is the nature of the typhoid poison? The 'yellow typhoid matter,' already referred to, Budd describes as made up of nucleated cells. The term 'germ-theory' does not, to my knowledge, occur once in the volume, possibly because of the opposition and ridicule[1] which that theory encountered in the English Medical Press. Over and over again Budd speaks of 'germs;' but it might be imagined that he used the word figuratively. Those who knew him, however, were well aware that this was not the case; and in the early part of the present volume, after describing the calamities incident to typhoid fever, he remarks: 'It is humiliating that issues such as these should be contingent on the powers of an agent so low in the scale of being that the mildew which springs on decaying wood must be considered high in comparison.' Four or five years ago, I, an outsider, ventured upon this ground of medical theory, for it involved no knowledge of medical practice, but simply a capacity to weigh evidence; and the evidence that epidemic diseases were parasitic appeared to me very strong. On June 9, 1871, I ventured to express myself thus: 'With their respective viruses you may plant typhoid fever, scarlatina, or smallpox. What are the crops that arise from this husbandry? As surely as a thistle rises from a thistle-seed, as surely as the fig comes from the fig, the grape from the grape, and the thorn from the thorn, so surely does the typhoid virus increase and multiply into typhoid fever, the scarlatina virus into scarlatina, the smallpox virus into smallpox. What is the conclusion that suggests itself here? It is this: that the thing which we vaguely call a virus is to all intents and purposes a *seed*; that, excluding the notion of vitality, in the whole range of chemical science you cannot point

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iderably abated [1876].

to an action which illustrates this perfect parallelism with the phenomena of life—this demonstrated power of self-multiplication and reproduction.'[1] It was the clear and powerful writings of William Budd, joined to those of the illustrious Pasteur, that won me to these views. It is partly with a view of stamping at a receptive moment salutary truths upon the public mind, but partly, also, through the desire of rendering justice to a noble intellect, which has been literally sacrificed to the public good, that I draw attention, not only to the masterly combination of observation and inference exhibited from beginning to end of Dr. Budd's volume, but also to the crowning fact, already published in the medical journals, and to which my attention was first drawn by my eminent friend Mr. Simon, that Dr. Klein has recently discovered the very organism which lies at the root of all the mischief, and to the destruction of which medical and sanitary skill will henceforth be directed.[2]

I am, Sir,
Your obedient servant,
John Tyndall.

Royal Institution: *Nov.* 6.

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[1] It was the considerations here mentioned that swayed me at the outset; it is they that most powerfully influence my convictions still. And they would remain if the causal relation between recently discovered organisms and epidemic disease were disproved to-morrow.—J. T., March 1876.

[2] Dr. Murchison gave this brief reference to Dr. Klein considerable prominence in his remarks before the Pathological Society on May 4, 1875. He did not grapple with the arguments of Dr. Budd, nor attempt to show why, when every condition laid down by himself for the production of typhoid fever is present, the fever fails to be produced. See p. [35.

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